PB-240 131

NEWS OF ENVIRONMENTAL RESEARCH IN CINCINNATI, JANUARY - DECEMBER 1974

National Environmental Research Center
Cincinnati, Ohio

March 1975

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	PB 240 131
EPA-670/9-75-003		

4. TITLE AND SUBTITLE	5. REPORT DATE
NEWS OF ENVIRONMENTAL RESEARCH IN CINCINNATI January - December 1974	March 1975; Issuing Date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Technical Information Staff, comp.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS National Environmental Research Center Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	10. PROGRAM ELEMENT NO. 1RA103 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same as above	13. TYPE OF REPORT AND PERIOD COVERED January - December 1974 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

See EPA-670/9-74-002, PB-230 935/AS

16. ABSTRACT

A series of reports on the following subjects: impact of environmental control technologies on the energy crisis; publications - 1973; advanced wastewater treatment plant at Piscataway, Maryland; identifying organic pollutants in water; survival of fecal coliforms and fecal streptococci in a sanitary landfill; sludge incineration and fuel conservation; producing protein while reducing waste; toxicity of wastewater disinfectants; BGM: a new cell line for recovering viruses from water; radiorespirometry: rapid toxicological screening of environmental pollutants; a swirl device for regulating and concentrating combined sewer overflows; recreational water quality criteria; granular media filtration of secondary effluent; and coal refuse disposal in the eastern United States.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment, Waste disposal, Leaching, Organic compounds, Water pollution, Water quality, Sludge, Sewage, Incinerators, Fuel consumption, Cellulose, Proteins, Waste water, Toxicity, Disinfectants, Chlorine, Viruses, Tissue culture, Combined sewers, Overflows, Separators, Swimming, Epidemiology, Filtration, Effluents, Coal, Refuse, Refuse disposal, Gas chromatography, Pilot plants	Energy conservation, Energy consumption, Environmental documents, Waste water treatment, Organic compounds measurement, Sanitary landfill, Solid waste, Solid waste disposal, Organic pollutants, Protein production, Environmental pollution, Radiorespirometry, Sewer overflows, Swirl regulator/concentrator, Storm flows, Recreational water quality, Influents, Acid mine drainage	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	69
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE $4.25

EPA Form 2220-1 (9-73)

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. Department of Commerce
Springfield, VA. 22151

PRICES SUBJECT TO CHANGE

078127

EPA-670/9-75-003
March 1975

NEWS OF ENVIRONMENTAL RESEARCH IN CINCINNATI

January - December 1974

Compiled by

Technical Information Staff

Program Element 1RA103

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REVIEW NOTICE

The National Environmental Research Center--Cincinnati has reviewed this report and approved its publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

As part of these activities, each of the laboratories of NERC-Cincinnati outlines various research problems of their concern and elaborate on how they are being handled. Topics of interest have included research concerning advanced waste treatment, industrial waste treatment, solid and hazardous waste, water supply research, methods development and quality assurance research, and environmental toxicology research.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

CONTENTS

Impact of Environmental Control Technologies on the Energy Crisis 1
T. W. Bendixen and G. L. Huffman

Publications-1973 9
R. Elaine Cole and Ann H. Tate

Advanced Wastewater Treatment Plant at Piscataway, Maryland 16
Thomas P. O'Farrell

Identifying Organic Pollutants in Water 19
J. W. Eichelberger, L. E. Harris, and W. L. Budde

Survival of Fecal Coliforms and Fecal Streptococci in a Sanitary Landfill 23
Janet C. Blannon and Mirdza L. Peterson

Sludge Incineration and Fuel Conservation 27
R. A. Olexsey and J. B. Farrell

Producing Protein While Reducing Waste 31
Charles J. Rogers

Toxicity of Wastewater Disinfectants 35
Robert B. Dean

BGM: A New Cell Line for Recovering Viruses from Water 39
Daniel R. Dahling, Gerald Berg, Donald Berman, and Robert S. Safferman

Radiorespirometry: Rapid Toxicological Screening of Environmental Pollutants 43
S. D. Lee, R. M. Danner, L. McMillan, W. Moore, Jr., and J. F. Stara

A Swirl Device for Regulating and Concentrating Combined Sewer Overflows 47
Richard Field

Recreational Water Quality Criteria 51
Victor J. Cabelli and Leland J. McCabe

Granular Media Filtration of Secondary Effluent 55
James F. Kreissl

Coal Refuse Disposal in the Eastern United States . . . 59
John F. Martin

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

PROGRAM COORDINATION STAFF (Office of Director)

January 11, 1974

IMPACT OF ENVIRONMENTAL CONTROL TECHNOLOGIES ON THE ENERGY CRISIS*

SUMMARY

Although environmental concern has caused and will cause some small increases in U.S. energy demand and has restricted our energy supply to some extent, other factors have been more significant. Not the least of these has been the public's continually escalating demand for energy.

Four major environmental control practices exemplify the magnitude of the impact on energy demand: (1) emission control for automobiles; (2) sulfur dioxide (SO_2) control for power plants; (3) municipal wastewater treatment; and (4) solid waste collection and disposal.

The energy required to operate the last three control processes would be only 1.04 percent of today's total U.S. demand, even in the most power-consuming example studied. This low energy-consumption rate assumes all the Nation's power plants have SO_2 scrubbers, all municipal wastewaters are treated to the tertiary level, and all municipal solid waste is properly collected and landfilled. This power consumption would approximate 747 trillion Btu's per year — less than twice the amount of energy used in 1968 to air condition our homes.

Regarding the energy needed for emission control for automobiles, the 10 percent average loss in fuel economy due to first-generation control devices should very nearly be recouped in the 1975 model year. At that time, engine modifications compatible with the new catalytic converter emission control devices should make this possible.

Environmental concern has had an impact on energy supply. If we are to have clean air and water, caution must influence how we supply our energy and prudence must influence how we use our energy.

INTRODUCTION

A current popular pastime is for each segment of our society to accuse the others of causing the Energy Crisis. Let us admit that most, if not all, of the accusations being made cannot be categorically denied. We all share part of the blame.

It is time to recognize that practically everything we do, including environmental control, has an energy cost. Bringing this to the public's attention may be a benefit of the Energy Crisis. Environmental control does have a cost; we should recognize it, base our buying and living preferences accordingly, and recognize that the costs must be paid.

This paper is not intended to explore all of the complex reasons for the Energy Crisis; rather it is to examine just the effect that environmental concerns may have had by increasing energy demands on one hand and restricting supply on the other. Many other factors have been more significant in causing this problem.

CONVERSIONS USED IN THIS PAPER

1 quadrillion = 10^{15} = 1,000,000,000,000,000

1 trillion = 10^{12} = 1,000,000,000,000

1 Barrel of Oil = 6×10^6 Btu

1 Ton Coal = 25×10^6 Btu

1 kwh = 10,500 Btu

1 Mw = 1000 kw

*This paper was co-authored by T. W. Bendixen, Environmental Consultant, and G. L. Huffman, Research Chemical Engineer with EPA's NERC-Cincinnati. Inspiration for the paper, and technical guidance throughout its development, came from Dr. A. W. Breidenbach, Director of NERC-Cincinnati. The contributions of EPA's R. M. Clark, K. Clough, Mrs. M. G. Curry, M. H. Friedman, W. J. Benoit, and L. W. Lefke are also acknowledged. EPA's research center in Cincinnati, Ohio, has as its major theme the development of pollution control technology.

THE ENERGY DEMAND PICTURE

Cumulative energy demand from now to the year 2000 will be on the order of 4000 quadrillion Btu's. The magnitude of identified recoverable fossil fuels in the United States is on the order of 10,300 quadrillion Btu's.[1] Therefore, the reserves are greater than projected use by about a factor of two and one-half.

The demand for energy in the United States doubled in the 22 years between 1950 and 1972. In 1950, it approximated 35 quadrillion (10^{15}) Btu's per year, and by 1972, about 72 quadrillion Btu's per year. Figure 1 shows the rate of growth by major energy sources over this period.[2] Using information from this figure, it can be shown that, since 1950, the per capita total energy consumption in this country has increased by 50 percent (from about 230 to 340 million Btu's per year per person).[2] The public's preferences, accelerated by effective advertising marketing techniques, have caused much of this increase in demand; the ground-swell for environmental protection did not swing into full gear until mid-1970, and its contribution to this increase is minimal.

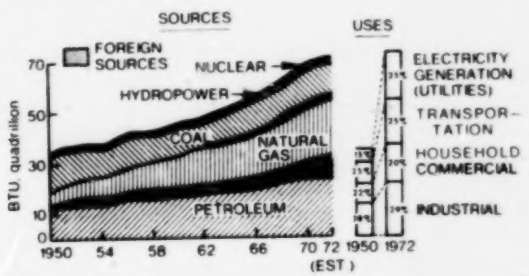

Figure 1. Major sources supplying U.S. demand for energy between 1950 and 1972. U.S. energy requirements have doubled during the 1950-72 period. The use column indicates the transition from an industrial economy to a service-oriented economy. (Adapted from Ref. 2.)

One of the fastest growing U.S. energy demands is for electrical power. From 1950 to 1972, the generation of electricity went up by a factor of about 3.5, from about 5.2 to 18.7 quadrillion Btu's per year.

In 1972, demand for energy was supplied in the following manner: about 46 percent (32.8 quadrillion Btu's) was supplied by about 6 billion barrels of petroleum, 1.7 billion barrels of which came from imports; about 32 percent (23.3 quadrillion Btu's) was supplied by natural gas; 17 percent, by coal; 4 percent, by hydropower; and 1 percent, by nuclear power.[2-4]

Figures 2a and 2b depict the supply and use of oil and coal, respectively, over the last 22 years. Also shown are the gross percentages of these resources that went for the four major end uses of energy (electricity generation, household and commercial, industrial, and transportation).[2]

THE END USES OF OUR ENERGY

There are hundreds of uses for energy, but only a relatively few account for the major portion of

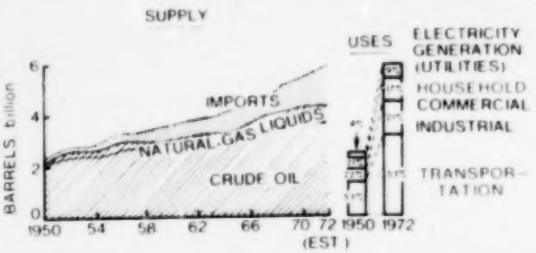

Figure 2a. Supply and use of petroleum in the United States between 1950 and 1972. Transportation and energy are the catalytic agents of a dynamic post-industrial society. Note the high percentage of total liquid fuels required for air, land, and water transportation. Use of liquid fuels will continue to rise rapidly in the future. (Adapted from Ref. 2.)

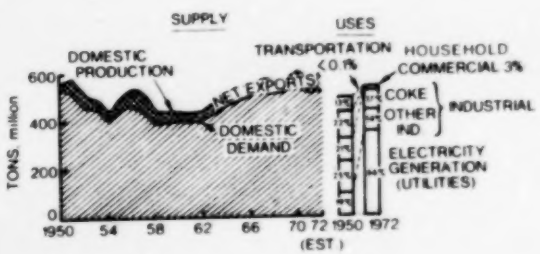

Figure 2b. Supply and use of bituminous, anthracite, and lignite coal in the United States from 1950 to 1972. Coal is the most abundant, indigenous, and dependable source of energy in the United States for contemporary methods of producing power. National efforts strive for safe mining, reclamation of disturbed mining areas, and clean and effective use of this abundant resource. (Adapted from Ref. 2.)

the Nation's total energy consumption. The 12 uses shown in Table 1 accounted for over 97 percent of the consumption in 1968.[4] As might be expected, transportation accounted for a major share, about 25 percent, and the first 6 uses accounted for over 84 percent.

TABLE 1. MAJOR END USES FOR ENERGY, 1968 DATA[4]

Type of use	Percent of total U.S. energy consumption
Transportation (fuel; excludes lubes and greases)	24.9
Space heating (residential, commercial)	17.9
Process steam* (industrial)	16.7
Direct heat* (industrial)	11.5
Electric drive (industrial)	7.9
Feedstocks, raw materials (commercial, industrial, transportation)	5.5
Water heating (residential, commercial)	4.0
Air conditioning (residential, commercial)	2.5
Refrigeration (residential, commercial)	2.2
Lighting (residential, commercial)	1.5
Cooking (residential, commercial)	1.3
Electrolytic processes (industrial)	1.2
Total	97.1

*Includes some use for space heating, probably enough to bring total space heating to about 20 percent.

The energy use among residential and commercial building services, industrial processes, and transportation is further broken down in Table 2.[4] Within this categorization, industrial uses accounted for about 41 percent of the total in 1968. The sum of space heating and air conditioning in the residential and commercial sectors accounted for 18 to 20 percent.

The annual rate of growth for each sector is about 4 or 5 percent and is quite comparable to the growth rate of the national total. Among the clothes drying, refrigeration, and air conditioning subcategories, however, the growth is two to four times the national rate.

An interesting end-use classification (Table 3) illustrates the electrical consumption for some selected small appliances. These data reflect the influence of the advertising industry on the public's decisions in buying convenience items; note that the use of electric toothbrushes and carving knives each consume about 1 trillion Btu's per year.[4]

POTENTIAL CONTRIBUTIONS OF ENVIRONMENTAL CONTROL TO ENERGY DEMAND

In an attempt to put into perspective the potential impact of various pollution control processes on the demand for energy in this country, we will examine the following individual processes:

- Emission Control for Automobiles
- SO_2 Control for Power Plants
- Wastewater Treatment
- Solid Waste Collection and Disposal

Although these four processes are not the only contributors to the total demand for energy by environmental control, they do represent four of the major ones.

Emission Controls for Automobiles

In 1970, 85 million cars consumed about 14 percent of the Nation's total energy demand, almost 10 quadrillion Btu's per year or about 1.6 billion barrels per year of fuel. While logging 1.1 trillion miles on our roads, all our motor vehicles (cars, trucks, and buses) consumed that year the energy equivalent of about 2.1 billion barrels of petroleum or about 40 percent of our total oil consumption.[5]

The consumption of these large quantities of fuel have made the automobile and our other motor vehicles a significant source of pollution. On a national basis, motor vehicles contribute to the atmosphere 66 percent of the total man-made carbon monoxide emissions, 48 percent of the hydrocarbon emissions, and 40 percent of the emissions of oxides of nitrogen.[6]

Many factors influence the automobile's fuel economy characteristics. The trend toward ever-increasing automobile size and weight, the upsurge in demand for car air-conditioning units, the switch over from manual to automatic transmissions, and the introduction of emission control devices have all influenced automobile fuel economy.

Of these, vehicle weight is the single most important factor. This is one of the major findings of a study in which fuel economy data from more than 4,000 cars were analyzed. As can be seen by Figure 3, a 5,000-pound vehicle exhibits 50 percent lower fuel economy than does a 2,500-pound vehicle — or, expressed another way, a 5,000 pound car consumes 100 percent more fuel per mile than does a 2,500 pound one.[7]

In 1971, over 60 percent of all new cars were sold with factory-equipped air conditioning;[8] the average loss in fuel economy associated with air conditioning is about 9 percent. Stop-and-go driving

TABLE 2. ENERGY CONSUMPTION IN THE UNITED STATES BY END USE BETWEEN 1960 and 1968*†

Sector and end use	Consumption, trillions of Btu		Annual rate of growth, %	Percent of national total	
	1960	1968		1960	1968
Residential					
Space heating	4,848	6,675	4.1%	11.3%	11.0%
Water heating	1,159	1,736	5.2	2.7	2.9
Cooking	556	637	1.7	1.3	1.1
Clothes drying	93	208	10.6	0.2	0.3
Refrigeration	369	692	8.2	0.9	1.1
Air conditioning	134	427	15.6	0.3	0.7
Other	809	1,241	5.5	1.9	2.1
Total	7,968	11,616	4.8‡	18.6	19.2
Commercial					
Space heating	3,111	4,182	3.8	7.2	6.9
Water heating	544	653	2.3	1.3	1.1
Cooking	98	139	4.5	0.2	0.2
Refrigeration	534	670	2.9	1.2	1.1
Air conditioning	576	1,113	8.6	1.3	1.8
Feedstock	734	984	3.7	1.7	1.6
Other	145	1,025	28.0	0.3	1.7
Total	5,742	8,766	5.4‡	13.2	14.4
Industrial					
Process steam	7,646	10,132	3.6	17.8	16.7
Electric drive	3,170	4,794	5.3	7.4	7.9
Electrolytic processes	486	705	4.8	1.1	1.2
Direct heat	5,550	6,929	2.8	12.9	11.5
Feedstock	1,370	2,202	6.1	3.2	3.6
Other	118	198	6.7	0.3	0.3
Total	18,340	24,960	3.9‡	42.7	41.2
Transportation					
Fuel	10,873	15,038	4.1	25.2	24.9
Raw materials	141	146	0.4	0.3	0.3
Total	11,014	15,184	4.1‡	25.5	25.2
National total	43,064	60,526	4.3‡	100.0	100.0

*Electric utility consumption has been allocated to each end use.
†The source is the Stanford Research Institute, which used Bureau of Mines and other sources.
‡Totals represent weighted average values.

in hot weather with an air conditioner can result in a 20 percent fuel economy loss.

Using an automatic transmission rather than manually shifting results in a fuel economy loss ranging from 2 to 15 percent.

The average fuel economy of 1973 vehicles with emission controls is about 10 percent less than vehicles without controls. The loss due to emission controls varies significantly with vehicle weight; the fuel economy of lighter cars improves about 3 percent, and heavy vehicles lose up to 18 percent.

Catalytic converters will probably be the pollution control device affixed to most 1975 model automobiles to meet the emission standards sched-

TABLE 3. ELECTRICAL CONSUMPTION OF SELECTED SMALL APPLIANCES, 1969*

Appliance	Annual kwh per item†	Number of items (millions)‡	Total annual consumption (billion kwh)	Total annual consumption (trillion Btu)
Bed coverings	147	27.0	3.97	42.6
Blenders	15	16.0	0.24	2.6
Broilers	100	14.0	1.40	15.0
Clocks	17	55.0	0.94	10.1
Coffee makers, automatic	106	50.0	5.30	56.7
Dehumidifiers	377	3.8	1.43	15.3
Fans (circulating)	43	75.0	3.23	34.5
Food disposers	30	13.5	0.41	4.4
Frypan skillets	186	33.0	6.14	65.7
Hair dryers	14	22.5	0.32	3.4
Heaters (portable)	176	17.0	2.99	32.0
Hot plates	90	15.0	1.35	14.4
Humidifiers	163	4.0	0.65	7.0
Irons	144	57.0	8.21	87.8
Knives (carving)	8	13.0	0.10	1.1
Mixers	13	49.0	0.64	6.8
Radios	86	57.0	4.90	52.4
Shavers	18	24.0	0.43	4.6
Toasters	39	54.0	2.11	22.6
Toothbrushes	5	15.0	0.08	0.9
Vacuum cleaners	46	53.0	2.44	26.1
Total			47.28	506.0

*Source is Stanford Research Institute.[7]
†Source is Edison Electric Institute (based on data from a limited sample).
‡Estimated number in households in mid-1969. From Merchandising Week, February 23, 1970; SRI estimates.

uled to take effect that year. Catalytic converters effect the oxidation of unburned hydrocarbons and carbon monoxide to carbon dioxide and water. Despite many past predictions of fuel economy loss as the result of meeting the 1975-1976 standards, it now appears that vehicles equipped with catalytic converters will have better (up to 15 percent) fuel economy than 1973 vehicles.[8] In testimony before the Senate Public Works Committee (November 5, 1973), a General Motors representative indicated that their 1975 model vehicles would, on the average, achieve a 13 percent fuel economy gain over their 1973 and 1974 model vehicles.[8]

Not only will we have cleaner air with the 1975 model cars, we will also have improved average gas mileage over 1973 models. Future trends toward smaller cars with manual transmissions and fewer

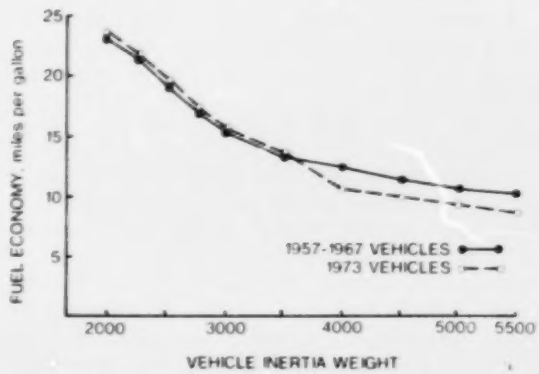

Figure 3. Fuel economy versus inertia weight for uncontrolled pre-1968 and controlled 1973 automobiles.[8]

5

optional items will further improve average gas mileage.

Sulfur Dioxide (SO_2) Control for Power Plants

In 1968, about 10 million tons of SO_2 were emitted to the atmosphere from coal and oil-burning power plants.[8]

From the data presented in Figures 2a and 2b, it has been estimated that in 1972, about 8.6 quadrillion Btu's per year in energy were extracted from coal and about 3.2 quadrillion from oil to produce about 1.1 billion megawatt-hours of electricity. This would correspond to about 130,000 megawatts (Mw) of total power plant capacity operating 100 percent of the time (8,760 hours per year).

Various processes (some nonregenerative, some regenerative) to remove SO_2 from power-plant flue gases via scrubbing techniques are being developed. With the nonregenerative type (e.g., the lime and limestone scrubbing processes), the reaction product exiting in the scrubbing slurry is ultimately discarded. With the regenerative type (e.g., the ammonia scrubbing conversion-to-fertilizer process and the magnesia scrubbing conversion-to-sulfuric-acid process), the scrubber reaction product is converted to a useful end product, and the scrubbing liquor is continually replenished by regenerated material.

Very few SO_2 scrubbers of either type have actually been installed at power plants. If, however, SO_2 scrubbers were installed on all of today's power plant capacity (1.1×10^9 megawatt-hours per year of actually-used capacity) and if the plants were fed 3.5 percent sulfur fuels, the following would result:

- About 62 trillion Btu's per year would be required to supply the power if the limestone-scrubbing process were selected;[9] this represents about 0.09 percent of the total U. S. demand for energy;
- About 490 trillion Btu's per year would be required to supply the power and the heat if a regenerative, fertilizer-producing, ammonia-scrubbing process were selected;[10] this represents about 0.68 percent of the total energy demand.

These examples approximate the two extremes in energy requirement needed by the various SO_2 control processes being developed. With the limestone-scrubbing process, the total energy required for complete SO_2 control in the country would be of the same order of magnitude as that for operating all our frypan skillets in 1969 (see Table 3). The energy requirements for the ammonia-scrubbing, fertilizer-producing process would approximate those for operating all of the selected small appliances shown in Table 3, i.e., 506 trillion Btu's per year.

These relatively small energy demands associated with SO_2 pollution control are an extremely small price to pay when it is realized that flue-gas desulfurization via scrubbing lets us burn high-sulfur-content fuel without damaging our lungs.

Wastewater Treatment

The energy demand associated with wastewater treatment depends on the degree of treatment and the unit processes involved. The major use of energy is for electricity to operate equipment such as pumps, scrapers, compressors, chlorinators, etc. An estimate of the 1968 consumption of electrical energy for various municipal waste treatment processes contained values from 0.018 kilowatt-hour per day per person for minor treatment to 0.226 for tertiary treatment.[11] The average value was 0.057. For the population served at that time, the total electrical energy consumption was about 7.5 $\times 10^9$ kilowatt-hours per day or about 29 trillion Btu's per year. This represents about 0.04 percent of the total U.S. demand for energy or about 70 percent of the annual electricity consumed by electric blankets in 1968 (see Table 3). If today's total population were served by tertiary treatment, the electrical energy consumption for municipal water pollution control would approximate 182 trillion Btu's per year or 0.25 percent of today's energy demand.

One estimate of the total operational energy demand for primary and secondary treatment for all municipal plus industrial wastewater in the United States is about 290 trillion Btu's per year or 0.4 percent of total energy use. If all wastewater were to be treated to a tertiary level, the total operational energy demand would be about 0.8 percent of the total energy demand.[12]

Solid Waste Collection and Disposal

In the same study,[12] a reasonable average energy value for solid waste collection, transportation, and disposal in landfills is given as 300,000 Btu's per ton. If all 250 million tons of residential, commercial, and institutional solid waste produced in the United States in 1970 had been properly landfilled, the total energy cost would have been about 75 trillion Btu's (about 0.11 percent of total energy used).[12]

However, if only 10 percent of this solid waste had been converted to power via heat recovery schemes, then about 260 trillion Btu's of electrical energy equivalence could have been generated. This would have represented a savings of about 0.4 percent of our total energy consumption.[12] Therefore, about four times as much energy could have been

generated from recovering the heat value from 10 percent of our solid waste as was needed to collect and landfill all of our solid waste.

POTENTIAL CONTRIBUTION OF ENVIRONMENTAL CONTROL TO ENERGY SUPPLY

Although the four examples described here illustrate that pollution control processes used to protect the environment will contribute very little to the overall national demand for energy — the environmental movement has had an influence on the supply of energy. If we are to have clean air and water, environmental considerations must influence the supply of today's and tomorrow's energy requirements.

Let there be no mistake about it: the environmental concern has had an impact on our current Energy Crisis. Concern for the well-being of the Alaskan territory, plus the mandated requirements of the National Environmental Protection Act, delayed the go-ahead signal on the Alaskan Pipeline project. Also, let there be no mistake about it: the delay will minimize the environmental insult to the area. Similarly, environmental concern about incorporating adequate safeguards into the design of nuclear power plant facilities has contributed to the delays in starting new plant construction; there can be little disagreement, though, that this method of increasing our energy supply does warrant our closest scrutiny.

Implementing the Clean Air Act and the Federal Water Pollution Control Act has also influenced the supply side of the Nation's energy picture. For example, as a result of the Clean Air Act legislation, air quality standards for various air pollutants have been established and pollutant concentration levels were set to protect the people's health. The SO_2 standard created a perplexing problem for the power industry and for other industry: should they (1) switch over to low-sulfur fuels whose availability is limited and keyed to the precarious energy balance between fuel oil and gasoline and distillates; or (2) take a chance on the developing, but not fully developed, flue gas desulfurization techniques that permit the use of high-sulfur coal or oil but jeopardize the hundreds of millions of dollars invested in them.

The power industry, as well as other industry, opted for the former approach and adopted a "wait and see" stance on the latter, waiting for the flue gas scrubbing demonstration plants to exhibit their worth. As the result of taking the low-sulfur-fuel approach, the use of high-sulfur coal was cut back, low-sulfur coal and natural gas quickly became scarce, and increased emphasis on desulfurized fuel oil caused imbalances in the gasoline supply. These results, coupled with the Middle East oil embargo, are contributing factors to today's squeeze on energy supplies.

Suppose flue gas scrubbers had been installed on all our power plant and other industrial stack gas effluents and the attendant risks (the large dollar commitment on available but not necessarily completely acceptable technology) had been accepted — would we be in as serious an energy fix as we are in today?

Suppose, too, we and the automotive industry and the oil industry had recognized years ago (as the Europeans did) the energy supply and demand implications of our conscious decisions to continually strive for bigger and more power-consuming cars — would we be in as serious an energy fix as we are in today?

Suppose we had recognized years ago (as the Europeans did) the worth of recovering the heat value contained in our otherwise discarded solid waste and had converted some of it to usable electricity — would we be in as serious an energy fix as we are in today?

CONCLUSIONS

- Since 1950, the per capita total energy consumption in this country has increased by 50 percent; much of the increase is attributable to the public's rise in affluence; little of the increase is attributable to environmental control systems.
- The temporary 10 percent loss in fuel economy due to today's first-generation automobile pollution control devices will be gained back when the second-generation devices, catalytic converters, are used.
- The energy required to operate SO_2 control processes at power plants, tertiary municipal wastewater treatment plants, and solid waste collection and disposal operations will range from about 0.45 to 1.04 percent of today's total energy demand. The value of 1.04 is only about 50 percent of the amount of energy needed for air conditioning our homes and offices in 1968. Recovery of electrical energy from 11 percent of the Nation's solid waste would restore the 0.45 percent energy loss for these environmental controls of the future — recovery from 26 percent of our solid waste would supply the 1.04 percent demand.
- Maintenance of environmental quality does have an energy cost, both on the supply and demand side; it is relatively small; it is well worth the price.

REFERENCES

1. Risser, H. E., "The U.S. Energy Dilemma: The Gap Between Today's Requirements and Tomorrow's Potential," Environmental Geology Notes, Number 64, Illinois State Geological Survey, July 1973.
2. National Commission on Materials Policy, "Material Needs and the Environment Today and Tomorrow," Final Report, June 1973.
3. Darmstadter, J., et al., for Resources for the Future, Inc., "Energy in the World Economy: A Statistical Review of Trends in Output, Trade, and Consumption Since 1925," Johns Hopkins Press, Baltimore, 1971, page 13.
4. Stanford Research Institute for the Office of Science and Technology, "Patterns of Energy Consumption in the United States," January 1972. (Available from NTIS as PB 212 776.)
5. Sansom, R. L., "The Automobile as a Social Machine," an address before the International Automotive Engineering Congress and Exposition, Detroit, Michigan, January 10, 1973.
6. U.S. Environmental Protection Agency, Office of Air and Water Programs, "A Report on Automotive Fuel Economy," October 1973.
7. Train, R. E., Statement before the Subcommittee on Public Health and Environment, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, December 3, 1973.
8. Morris, D. N. (Rand Corporation), "Future Energy Demand and Its Effect on the Environment," a report prepared for the National Science Foundation, September 1972, page 27.
9. Tennessee Valley Authority, "Sulfur Oxide Removal from Power Plant Stack Gas: Use of Limestone in Wet-Scrubbing Process," Final Report to Department of Health, Education, and Welfare's National Air Pollution Control Administration, 1969, page 94. (Available from NTIS as PB 183 908.)
10. Tennessee Valley Authority, "Sulfur Oxide Removal from Power Plant Stack Gas: Ammonia Scrubbing, Production of Ammonium Sulfate and Use as an Intermediate in Phosphate Fertilizer Manufacture," Final Report to Department of Health, Education, and Welfare's National Air Pollution Control Administration, 1970, page 247. (Available from NTIS as PB 196 804.)
11. Smith, R., "Electrical Power Consumption for Municipal Wastewater Treatment," EPA-R2-73-281, July 1973. (Available from NTIS as PB 223 360/9WE.)
12. Hirst, E., "The Energy Cost of Pollution Control," Environment, 14(8):37-44, October 1973.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974—758-495/1239

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U S ENVIRONMENTAL PROTECTION AGENCY
EPA 335

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

TECHNICAL INFORMATION STAFF
(Office of the Director)
February 1, 1974

PUBLICATIONS—1973

Compiled by: R. Elaine Cole and Ann H. Tate*

This issue provides a record of publications issued by and through the National Environmental Research Center, Cincinnati, in 1973. The research output represented here is the product of NERC investigators and extramural project directors of grant or contract efforts implemented through the Cincinnati Center.

The newsletter lists the titles of reports, journal and symposia articles, newsletters, and other special reports. Speeches at technical meetings (not published in symposia proceedings) and manuscripts in press are not included in this compilation.

Additional copies of this bibliography are available from the Technical Information Staff, National Environmental Research Center, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Andrew W. Breidenbach, Ph.D., Director
National Environmental Research Center
Cincinnati, Ohio

JOURNAL AND SYMPOSIA CONTRIBUTIONS

Berg, G., "Concentration of Viruses from Seawater (Discussion)," published in Progress in Water Technology, S. H. Jenkins, editor, Volume 3, Pergamon Press, New York, 1973.

Berg, G., "Methods for Detecting Viruses in Environmental Waters – A Status Report," published in the Proceedings of the First Microbiology Seminar on Standardization of Methods, EPA-R4-73-022, 72-89, 1973.

Berg, G., "Microbiology – Detection and Occurrence of Viruses," Journal Water Pollution Control Federation, 45:1289-1294, June 1973.

Berg, G., Comments to Discussion Paper and Comments on "Reassessment of the Virus Problem in Sewage and in Surface and Renovated Waters," published in Progress in Water Technology, S. H. Jenkins, editor, Volume 3, Pergamon Press, New York, 1973.

Bernstein, I. L., and R. S. Safferman, "The Biomedical Impact of Algae," Carolina Tips, 36(12):45-47, October 1, 1973.

*Mrs. Cole and Mrs. Tate are members of the Technical Information Staff, NERC-Cincinnati (513/684-8260).

Bernstein, I. L., and R. S. Safferman, "Clinical Sensitivity to Green Algae Demonstrated by Nasal Challenge and in vitro Tests of Immediate Hypersensitivity," Journal Allergy and Clinical Immunology, 51:22-28, January 1973.

Blanchard, R. L., E. L. Kaufman, and H. M. Ide, "Lead-210 Blood Concentration as a Measure of Uranium Miner Exposure," Health Physics, 25:129-133, August 1973.

Bloch, W. N., Jr., S. Lassiter, J. F. Stara, and T. R. Lewis, "Blood Rheology of Dogs Chronically Exposed to Air Pollutants," Toxicology and Applied Pharmacology, 25:576-581, 1973.

Bordner, R. H., "Quality Control: A State-of-the-Art," published in the Proceedings of the First Microbiology Seminar on Standardization of Methods, EPA-R4-73-022, 170-194, 1973.

Buelow, R. W., J. K. Carswell, and J. M. Symons, "An Improved Method for Determining Organics by Activated Carbon Adsorption and Solvent Extraction. Part I," Journal American Water Works Association, 65:57-73, January 1973.

Buelow, R. W., J. K. Carswell, and J. M. Symons, "An Improved Method for Determining Organics by Activated Carbon Adsorption and Solvent Extraction. Part II. Test Method,"

Journal American Water Works Association, 65:195-199, March 1973.

Bull, R. J., and S. D. Lutkenhoff, "Early Changes in Respiration, Aerobic Glycolysis and Cellular NAD(P)H in Slices of Rat Cerebral Cortex Exposed to Elevated Concentrations of Potassium," Journal of Neurochemistry, 21:913-922, 1973.

Bull, R. J., and J. T. Cummins, "Influence of Potassium on the Steady-State Redox Potential of the Electron Transport Chain in Slices of Rat Cerebral Cortex and the Effect of Ouabain," Journal of Neurochemistry, 21:923-937, 1973.

Bull, R. J., and J. T. Cummins, "The Potassium Dependence of the Cytochrome Redox Potential of Brain Slices," published in the Proceedings Society for Neuroscience, Third Annual Meeting Program and Abstracts, San Diego, California, p 383, November 7-11, 1973.

Bunch, R. L., "The Eutrophication Control Program of the Organization for Economic Cooperation and Development," AIChE Symposium Series 129, Water – 1972, 69:263-268, 1973.

Cabelli, V. J., "The Occurrence of Aeromonads in Recreational Waters," Abstracts of the Annual Meeting of the American Society for Microbiology, 73rd Annual Meeting, Miami Beach, Florida, May 6-11, 1973, G39, 1973.

Caldwell, J. S., R. J. Lishka, and E. F. McFarren, "Evaluation of a Low Cost Arsenic and Selenium Determination at Microgram/Liter Levels," Journal American Water Works Association, 65:731-735, November 1973.

Carnes, R. A., J. U. Doerger, and H. L. Sparks, "Polychlorinated Biphenyls in Solid Waste and Solid Waste Related Materials," Archives of Environmental Contamination and Toxicology, 1(1):27-35, 1973.

Carswell, J. K., R. W. Buelow, and J. M. Symons, "An Improved Method of Measuring Organics in Drinking Water by Activated Carbon Adsorption and Solvent Extraction," published in the Proceedings Fifteenth Water Quality Conference, Organic Matter in Water Supplies: Occurrence, Significance, and Control, University of Illinois, Urbana, Illinois, 73-80, February 7-8, 1973.

Ciancia, J., "New Waste Treatment Technology in the Metal Finishing Industry," Plating, 60:1037-1042, October 1973.

Clark, R. M., "Measures of Efficiency in Solid Waste Collection," Journal of the Environmental Engineering Division, ASCE, 99(EE4):447-459, August 1973.

Clark, R. M., "Solid Waste: Management and Models," published in Models for Environmental Pollution Control, R. A. Deininger, editor, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, Chap. 14, 269-305, 1973.

Cohen, A. L., "Dependence of Hi-Vol Measurements on Airflow Rate," Environmental Science & Technology, 7:60-61, January 1973.

Cohen, J. M., and I. J. Kugelman, "Wastewater Treatment – Physical and Chemical Methods," Journal Water Pollution Control Federation, 45:1027-1038, June 1973.

Craun, G. F., and L. J. McCabe, "Review of the Causes of Waterborne-Disease Outbreaks," Journal American Water Works Association, 65:75-84, January 1973.

Dean, R. B., "The Case Against Mercury," AIChE Symposium Series 129, Water – 1972, 69:279-283, 1973.

Dean, R. B., "Disposal and Reuse of Sludge and Sewage: What are the Options?" published in the Proceedings of Conference on Land Disposal of Municipal Effluents and Sludges, EPA-902/9-73-001, 19-29, March 12-13, 1973; also available in Compost Science, 14(5):12-14, September-October 1973.

Dorrler, J. S., "Sorbent System Development for Oil Spill Cleanup," published in the Proceedings Joint Conference on Prevention and Control of Oil Spills, Washington, D.C., pp 309-314, March 13-15, 1973.

Dotson, G. K., "Some Constraints of Spreading Sewage Sludge on Cropland," published in the Proceedings of Conference on Land Disposal of Municipal Effluents and Sludges, EPA-902/9-73-001, 67-77, March 12-13, 1973.

DuFour, A. P., V. J. Cabelli, and M. A. Levin, "Occurrence of *Klebsiella* Species in Wastes from a Textile Finishing Plant," Abstracts of the Annual Meeting of the American Society for Microbiology, 73rd Annual Meeting, Miami Beach, Florida, May 6-11, 1973, E16, 1973.

Feige, W. A., and E. L. Berg, "Full-Scale Mineral Addition at Lebanon, Ohio," Water & Sewage Works (Reference Number), 120:R79-R80, R82, R86, R88, R90, R92-R93, 1973.

Field, R. I., "Combined Sewer Overflows," Civil Engineering, 43:57-60, February 1973.

Field, R. I., and P. C. Weigel, "Urban Runoff and Combined Sewer Overflow," Journal Water Pollution Control Federation, 45:1108-1115, June 1973.

Gilbert, T. W., and R. A. Dobbs, "New Detector for Ion-Exchange Chromatography," Analytical Chemistry, 45(8):1390-1393, July 1973.

Goddard, H. C., "Environmental Policy as Economic Policy," Environmental Affairs, 2(3):630-637, 1973.

Gruenfeld, M., "Extraction of Dispersed Oil from Water for Quantitative Analysis by Infrared Spectrophotometry," Environmental Science and Technology, 7:636-639, 1973.

Gruenfeld, M., "Identification of Oil Pollutants: A Review of Some Recent Methods," published in the Proceedings Joint Conference on Prevention and Control of Oil Spills, Washington, D.C., pp 179-193, March 13-15, 1973.

Hornstein, B. A., "The Visibility of Oil-Water Discharges," published in the Proceedings Joint Conference on Prevention and Control of Oil Spills, Washington, D.C., pp 91-99, March 13-15, 1973.

Huffman, G. L., and D. J. Keller, "The Plastics Issue," published in Polymer Science and Technology, Volume 3: Polymers and Ecological Problems, James Guillet, editor, Plenum Press, New York, 155-167, 1973.

Johnson, H., "Hazardous Waste Disposal Studies," Waste Age, 4(2):38, 40, March/April 1973.

Kahn, B., "Environmental Radiation Monitoring," Transactions American Nuclear Society, 17:536, 1973.

Kahn, B., "Uses of Gamma-Ray Spectrometric Measurements in Radiological Surveillance at Nuclear Power Facilities," Transactions of American Nuclear Society, 16:67-68, 1973.

Klee, A. J., "Environmental Plastics Legislation in the U.S.: An Overview," S.P.E. Journal (Society of Plastics Engineers), 29:46-48, May 1973.

Kopfler, F. C., and J. Mayer, "Concentrations of Five Trace Metals in the Waters and Oysters (*Crassostrea virginica*) of Mobile Bay, Alabama," Proceedings of the National Shellfisheries Association, 63:27-34, June 1973.

Kopp, J. F., "l-Ephedrine in Chloroform as a Solvent for Silver Diethyldithiocarbamate in the Determination of Arsenic," Analytical Chemistry, 45(9):1786-1787, August 1973.

Kreissl, J. F., and J. M. Cohen, "Treatment Capability of a Physical-Chemical Package Plant," Water Research, 7:895-909, 1973.

Krieger, H. L., S. Gold, and B. Kahn, "Tritium Releases from Nuclear Power Stations," Tritium, A. A. Moghissi and M. W. Carter, editors, Messenger Graphics, Phoenix, Arizona, 557-564, 1973.

Levin, M. A., V. J. Cabelli, and A. P. DuFour, "Quantitation of Fecal Streptococci in the Marine Environment," Abstracts of the Annual Meeting of the American Society for Microbiology, 73rd Annual Meeting, Miami Beach, Florida, May 6-11, 1973, G69, 1973.

Lobring, L. B., and R. L. Booth, "Evaluation of the AutoAnalyzer II: A Progress Report," published in Advances in Automated Analysis (1972 Technicon International Congress), Mediad Inc., 8:7-10, 1973.

Logsdon, G. S., and J. M. Symons, "Mercury Removal by Conventional Water-Treatment Techniques," Journal American Water Works Association, 65:554-562, August 1973.

Longbottom, J. E., "The Use of a Programmable Calculator with Plotting Capabilities to Assist in the Chromatographic Computations," Journal Chromatographic Sciences, 11:13-16, January 1973.

Mason, W. T., Jr., C. I. Weber, P. A. Lewis, and E. C. Julian, "Factors Affecting the Performance of Basket and Multiplate Macroinvertebrate Samplers," Freshwater Biology, 3:409-436, 1973.

Middleton, F. M., "Organics in Water Supply – The Problem," published in the Proceedings Fifteenth Water Quality Conference on Organic Matter in Water Supplies: Occurrence,

Significance, and Control, University of Illinois, Urbana, Illinois, February 7, 1973, 1-14, 1973.
Moore, W. Jr., J. F. Stara, and W. C. Crocker, "Gastrointestinal Absorption of Different Compounds of ^{115m}Cadmium and the Effect of Different Concentrations in the Rat," Environmental Research, 6:159-164, 1973.
Moorman, W. J., J. J. Chmiel, J. F. Stara, and T. R. Lewis, "Comparative Decomposition of Ozone in the Nasopharynx of Beagles," Archives of Environmental Health, 26:153-156, March 1973.
Nadeau, R. J., and T. H. Roush, "A Salt Marsh Microcosm: An Experimental Unit for Marine Pollution Studies," published in Proceedings Joint Conference on Prevention and Control of Oil Spills, Washington, D.C., pp 671-683, March 13-15, 1973.
Rogers, C. J., and D. F. Spino, "Microbial Protein Production from Cellulosic Wastes," published in Symposium: Processing Agricultural and Municipal Wastes, G. E. Inglett, editor, Avi Publishing Company, Inc., Westport, Conn., Chapter 14, 161-171, 1973.
Strong, A. B., C. R. Porter, and B. Kahn, "Stable Strontium: Calcium Ratios in U.S. Bone and Total Diet Samples," published in Proceedings Second International Conference on Strontium Metabolism, Glasgow and Strontian, August 16-19, 1972. USAEC Report CONF-720818, 513-520, 1973.
Tardiff, R. G., "Health Standards for Metals in Drinking Waters," published in the Proceedings Heavy Metals in the Environment, Seminar conducted by Water Resources Research Institute, Oregon State University, 113-139, January 1973.
Tardiff, R. G., and M. Deinzer, "Toxicity of Organic Compounds in Drinking Water," published in the Proceedings Fifteenth Water Quality Conference on Organic Matter in Water Supplies: Occurrence, Significance, and Control, University of Illinois, Urbana, Illinois, February 7, 1973, 23-37, 1973.
Taylor, R. H., R. H. Bordner, and P. V. Scarpino, "Delayed Incubation Membrane Filter Test for Fecal Coliforms," Applied Microbiology, 25:363-368, March 1973.
Thomas, R. F., and R. L. Booth, "Selective Electrode Measurement of Ammonia in Water and Wastes," Environmental Science & Technology, 7:523-526, June 1973.
Venosa, A. D., and C. W. Chambers, "Bactericidal Effect of Various Combinations of Gamma Radiation and Chloramine on Aqueous Suspensions of *Escherichia coli*," Applied Microbiology, 25:735-744, May 1973.
Weber, C. I., "Biological Monitoring of the Aquatic Environment," Biological Methods for the Assessment of Water Quality, ASTM STP 528, American Society for Testing and Materials, 46-60, 1973.
Weber, C. I., "Recent Developments in the Measurement of the Response of Plankton and Periphyton to Changes in Their Environment," published in Bioassay Techniques and Environmental Chemistry, Gary Glass, editor, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, Chap. 5, 119-138, 1973.

REPORTS — In-House, Contract, and Grant

Akers, D. J., Jr., and E. A. Moss, "Dewatering of Mine Drainage Sludge - Phase II," EPA-R2-73-169; GPO No. EP1.23/2:73-b169; NTIS No. PB 221 145 (Project Officer: R. C. Wilmoth).
Albrecht, O. W., and R. G. McDermott, "Economic and Technological Impediments to Recycling Obsolete Ferrous Solid Waste," EPA-670/5-73-021; NTIS No. PB 223 034.
Allan, G. G., et al., "Wood Waste Reuse in Controlled Release Pesticides," EPA-670/2-73-034; NTIS No. PB 222 051 (Project Officer: C. A. Clemons).
Almgren, H., "Tertiary Treatment by Lime Addition at Santee, California," EPA-R2-73-206; NTIS No. PB 217 888 (Project Officer: G. Stern).
Andrews, J. F., and K. Kambhu, "Thermophilic Aerobic Digestion of Organic Solid Wastes," EPA-670/2-73-061; NTIS No. PB 222 396 (Project Officer: C. A. Clemons).
Bargman, R. D., and J. Borgerding, "Characterization of the Activated Sludge Process," EPA-R2-73-224; GPO No. EP1.23/2:73-224; NTIS No. PB 221 340 (Project Officer: R. Smith).
Barsom, G., "Lagoon Performance and the State of Lagoon Technology," EPA-R2-73-144; GPO (Project Officer: F. M. Middleton).
Bechtel Corporation, "Cost Estimating Guidelines for Wastewater Treatment Systems," EPA-R2-73-237; NTIS No. PB 215 516 (Project Officer: W. F. McMichael).
Beebe, R. L., "Activated Carbon Treatment of Raw Sewage in Solids - Contact Clarifiers," EPA-R2-73-183; GPO No. EP1.23/2:73-183; NTIS No. PB 219 883 (Project Officer: E. L. Berg).
Bender, D. F., M. L. Peterson, and H. Stierli, editors, "Physical, Chemical and Microbiological Methods of Solid Waste Testing," EPA-6700-73-001; NTIS No. PB 220 479.
Bianchi, R. A., and G. Henry, "The Development and Demonstration of An Underwater Oil Harvesting Technique," EPA-R2-73-205; GPO No. EP1.23/2:73-205; NTIS No. PB 221 431 (Project Office: EWQRL Staff).
Boettner, E. A., G. Ball, et al., "Combustion Projects from the Incineration of Plastics," EPA-670/2-73-049; NTIS No. PB 222 001 (Project Officer: C. A. Clemons).
Bond, R. G., et al., "Study of the Economics of Hospital Solid Waste Systems," EPA-670/5-73-020; NTIS No. PB 221 681 (Project Officer: O. W. Albrecht).
Booz Allen Applied Research Inc., "An Analysis of the Abandoned Automobile Problem," EPA-670/2-73-013; NTIS No. PB 221 879 (Project Officer: C. A. Clemons).
Booz Allen Applied Research Inc., "A Study of Hazardous Waste Materials, Hazardous Effects and Disposal Methods, Volume I," EPA-670/2-73-014; NTIS No. PB 221 465 (Project Officer: C. A. Clemons).
Booz Allen Applied Research Inc., "A Study of Hazardous Waste Materials, Hazardous Effects and Disposal Methods, Volume II," EPA-670/2-73-015; NTIS No. PB 221 466 (Project Officer: C. A. Clemons).
Booz Allen Applied Research Inc., "A Study of Hazardous Waste Materials, Hazardous Effects and Disposal Methods, Volume III," EPA-670/2-73-016; NTIS No. PB 221 467, PB 221 464-SET (Project Officer: C. A. Clemons).
Brown, J. C., L. W. Little, D. E. Francisco, and J. C. Lamb, "Methods for Improvement of Trickling Filter Plant Performance - Part I - Mechanical and Biological Optima," EPA-670/2-73-047a; GPO (Project Officer: R. L. Bunch).
Burchinal, J. C., "A Study of Institutional Solid Wastes," EPA-670/2-73-083; NTIS No. PB 223 345 (Project Officer: C. A. Clemons).

Burns, D. E., and G. L. Shell, "Physical-Chemical Treatment of a Municipal Wastewater Using Powdered Carbon," EPA-R2-73-264; GPO No. EP1.23/2:73-264 (Project Officer. J. J. Westrick).

Callihan, C. D., and C. E. Dunlap, "Single-Cell Protein from Waste Cellulose," EPA-670/2-73-095; NTIS No. PB 223 873/AS (Project Officer: C. J. Rogers).

Chung, N. K., "Investigation of Use of Gel Material for Mine Sealing," EPA-R2-73-135; GPO No. EP1.23/2:73-135; NTIS No. PB 221 247 (Project Officer: R. D. Hill).

City of St. Paul, Minnesota, "Temporary Detention of Storm and Combined Sewage in Natural Underground Formations," EPA-R2-73-242; GPO No. EP1.23/2:73-242 (Project Office: EWQRL Staff).

Clark, R. M., and J. I. Gillean, "Systems Simulation and Solid Waste Planning: A Case Study," EPA-670/5-73-012; NTIS No. PB 222 995.

Click, C. N., "The Feasibility of Flow Smoothing Stations in Municipal Sewage Systems," EPA-R2-73-138; GPO No. EP1.23/2:73-138; NTIS No. PB 221 246 (Project Officer: H. E. Bostian).

College of Agriculture and Environmental Science, Rutgers University – The State University of New Jersey, "Poultry Manure Disposal by Plow-Furrow-Cover," EPA-670/2-73-085; NTIS No. PB 223 430 (Project Officer: C. A. Clemons).

Condon, R. L., Jr., et al., "Instream Aeration to Control Dissolved Sulfides in Sanitary Sewers," EPA-670/2-73-024; NTIS No. PB 223 324 (Project Officer: J. N. English).

Converse, A. O., H. E. Grethlein, et al., "Acid Hydrolysis of Cellulose in Refuse to Sugar and Its Fermentation to Alcohol," EPA-670/2-73-011; NTIS No. PB 221 239 (Project Officer: C. J. Rogers).

Cross, R., A. Roberts, et al., "Oil Spills Control Manual for Fire Departments," EPA-R2-73-117; GPO No. EP1.23/2:73-117; NTIS No. PB 219 884 (Project Officer: F. J. Freestone).

Cross, R. H., III, "A Small Vacuum Oil Skimming System," EPA-R2-73-115; GPO No. EP1.23/2:73-115; NTIS No. PB 221 544 (Project Officer: F. J. Freestone).

Cunningham, J., "A Rapidly Deployable Oil Containment Boom for Emergency Harbor Use," EPA-R2-73-112; GPO No. EP1.23/2:73-112; NTIS No. PB 221 523 (Project Officer: F. J. Freestone).

Currier, R. A., and M. L. Laver, "Utilization of Bark Waste," EPA-670/2-73-005; NTIS No. PB 221 876 (Project Officer: R. A. Carnes).

Derick, C., and K. Logie, "Flow Augmenting Effects of Additives on Open Channel Flows," EPA-R2-73-238; GPO No. EP1.23/2:73-238 (Project Office: EWQRL Staff).

Derrington, R. E., D. H. Stevens, and J. E. Laughlin, "Enhancing Trickling Filter Plant Performance by Chemical Precipitation," EPA-670/2-73-060; GPO (Project Officer: R. C. Brenner).

Diesch, S. L., B. S. Pomeroy, et al., "Survival of Pathogens in Animal Manure Disposal," EPA-670/2-73-051; NTIS No. PB 222 337 (Project Officer: C. A. Clemons).

Dolan, F. X., and J. P. Bowersox, "Development of a Mobile System for Cleaning Oil-Contaminated Beaches," EPA-R2-73-233; GPO No. EP1.23/2:73-233 (Project Office: EWQRL Staff).

Duddles, G. A., and S. E. Richardson, "Application of Plastic Media Trickling Filters for Biological Nitrification Systems," EPA-R2-73-199; GPO (Project Officer: E. F. Barth).

Environmental Toxicology Research Laboratory, "Annual Report for Calendar Year 1972," EPA-670/1-73-036.

Eshleman, P. W., and R. A. Blase, "A Thermal Wave Flowmeter for Measuring Combined Sewer Flows," EPA-R2-73-145; GPO No. EP1.23/2:73-145 (Project Office: EWQRL Staff).

Esso Research and Engineering Company, "Oil Pollution Source Identification," EPA-R2-73-102; GPO No. EP1.23/2:73-102; NTIS No. PB 219 822 (Project Officer: B. Hornstein).

Field, R., "The Dual Functioning Swirl Combined Sewer Overflow Regulator/Concentrator," EPA-670/2-73-059.

Field, R., E. J. Struzeski, Jr., H. E. Masters, and A. N. Tafuri, "Water Pollution and Associated Effects from Street Salting," EPA-R2-73-257; GPO No. EP1.23/2:73-257.

Filar, H., Jr., "Carbon Adsorption and Electrodialysis for Demineralization at Santee, California," EPA-R2-73-240; NTIS No. PB 220 360 (Project Officer: G. Stern).

Filar, H., Jr., "Desal Ion Exchange for Demineralization at Santee, California," EPA-R2-73-239; NTIS No. PB 220 123 (Project Officer: G. Stern).

First, M. W., C. A. Oviatt, et al., "Municipal Waste Disposal by Shipborne Incineration and Sea Disposal of Residues," EPA-670/2-73-017; NTIS No. PB 221 684 (Project Officer: C. A. Clemons).

Fleischer, L. R., "Investigation of Corrosion Deposition Phenomena on Gas Turbine Blades," EPA-670/2-73-006; NTIS No. PB 221 095 (Project Officer: C. A. Clemons).

Fookson, A., and G. Frohnsdorff, "The Nitrite-Accelerated Photochemical Degradation of Cellulose as a Pretreatment for Microbiological Conversion to Protein," EPA-670/2-73-052; NTIS No. PB 222 115 (Project Officer: C. J. Rogers).

Ford, C. T., and J. F. Boyer, Jr., "Treatment of Ferrous Acid Mine Drainage with Activated Carbon," EPA-R2-73-150; GPO No. EP1.23/2:73-150; NTIS No. PB 219 826 (Project Officer: E. F. Harris).

Foreman, J. W., and D. C. McLean, "Evaluation of Pollution Abatement Procedures, Moraine State Park," EPA-R2-73-140; GPO No. EP1.23/2:73-140; NTIS No. PB 221 337 (Project Officer: R. D. Hill).

Friel, J. V., R. H. Hiltz, et al., "Control of Hazardous Chemical Spills by Physical Barriers," EPA-R2-73-185; GPO No. EP1.23/2:73-185; NTIS No. PB 221 493 (Project Officer: I. Wilder).

Glover, G. E., and G. R. Herbert, "Microstraining and Disinfection of Combined Sewer Overflows - Phase II," EPA-R2-73-124; GPO No. EP1.23/2:73-124; NTIS No. PB 219 879 (Project Officer: R. Field).

Golueke, C. G., et al., "Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes," EPA-R3-73-031; NTIS No. PB 222 454 (Project Officer: C. A. Clemons).

Grove, C. S., and C. M. Antoni, "Studies on Modifications of Solid Industrial Wastes," EPA-670/2-73-065; NTIS No. PB 222 419 (Project Officer: C. A. Clemons).

Hais, A. B., J. B. Stamberg, and D. F. Bishop, "Alum Addition to Activated Sludge with Tertiary Solids Removal," EPA-670/2-73-037 GPO.

Heimburg, R. W., et al., "Incineration of Plastics Found in Municipal Wastes," EPA-670/2-73-087; NTIS No. PB 223 651/AS (Project Officer: C. A. Clemons).

Hoffman, D. A., "Pyrolysis of Solid Municipal Wastes," EPA-670/2-73-039; NTIS No. PB 222 015 (Project Officer: C. A. Clemons).

Hopfenberg, H. B., "Water Treatment by Membrane Ultrafiltration," EPA-R2-73-109; NTIS No. PB 220 685 (Project Officer: W. A. Schwartz).

Horstkotte, G. A., Jr., "Pilot-Demonstration Project for Industrial Reuse of Renovated Municipal Wastewater," EPA-670/2-73-064; GPO (Project Officer: C. A. Brunner).

Hortenstine, C. C., and D. F. Rothwell, "Composted Municipal Refuse as a Soil Amendment," EPA-670/2-73-063; NTIS No. PB 222 422 (Project Officer: C. C. Wiles).

Howes, J. R., C. F. Hall, et al., "The Effect of Processing Poultry Manure on Disease Agents," EPA-670/2-73-041; NTIS No. PB 222 148 (Project Officer: C. A. Clemons).

Huber. C. O., "Atomic Absorption Analysis of Phosphates in Water," EPA-670/2-73-079; NTIS No. PB 223 338 (Project Officer: R. L. Booth).

Iglar, A. F., and R. G. Bond, "Hospital Solid Waste Disposal in Community Facilities," EPA-670/2-73-048; NTIS No. PB 222 018 (Project Officer: C. A. Clemons).

International Research and Technology Corporation, "Problems and Opportunities in Management of Combustible Solid Wastes," EPA-670/2-73-056; NTIS No. PB 222 467 (Project Officer: O. W. Albrecht).

Kaiser, E. R., D. Kasner, et al., "Incineration of Bulky Refuse Without Prior Shredding," EPA-670/2-73-023; NTIS No. PB 221 731 (Project Officer: C. A. Clemons).

Kaminsky, E. L., W. F. Roberts, and J. C. Volk, Jr., "Marine Sanitation System Demonstration," EPA-R2-73-226; GPO No. EP1.23/2:73-226; NTIS No. PB 221 334 (Project Officer: W. J. Librizzi, Jr.).

Katz, B., "Removal of Oil from Under Piers," EPA-R2-73-116; GPO No. EP1.23/2:73-116; NTIS No. PB 221 545 (Project Officer: F. J. Freestone).

Katz, B., and R. Cross, "Use of Fire Streams to Control Floating Oil," EPA-R2-73-113; GPO No. EP 1.23/2:73-113; NTIS No. PB 221 543 (Project Officer: F. J. Freestone).

Kelly, J. A., "Radiolytic Hydrolysis of Cellulose," EPA-670/2-73-030; NTIS No. PB 221 877 (Project Officer: C. J. Rogers).

Krieger, H. L., and S. Gold, "Procedures for Radiochemical Analysis of Nuclear Reactor Aqueous Solutions," EPA-R4-73-014; NTIS No. PB 222 154.

Lackey, L. L., T. O. Jacobs, et al., "Public Attitudes Toward Hazardous Waste Disposal Facilities," EPA-670/2-73-086; NTIS No. PB 223 638/AS (Project Officer: N. B. Schomaker).

Leatherwood, J. M., "Utilization of Fibrous Wastes as Sources of Nutrient," EPA-670/2-73-090; NTIS No. PB 223 625/AS (Project Officer: C. J. Rogers).

Lieberman, M., "Oil Pollution Source Identification," EPA-R2-73-102; GPO No. EP1.23/2:73-102; NTIS No. PB 219 822 (Project Officer: B. Hornstein).

Linstedt, K. D., and E. R. Bennett, "Evaluation of Treatment for Urban Wastewater Reuse," EPA-R2-73-122; GPO (Project Officer: E. F. Barth).

McCarthy, L. T., Jr., I. Wilder, and J. S. Dorrler, "Standard Dispersant Effectiveness and Toxicity Tests," EPA-R2-73-201; GPO No. EP1.23/2:73-201; NTIS No. PB 221 548.

McHarness, D. D., and P. L. McCarty, "Field Study of Nitrification with the Submerged Filter," EPA-R2-73-158; GPO No. EP1.23/2:73-158; NTIS No. PB 219 878 (Project Officer: E. F. Barth).

Maier, W. J., "Biological Removal of Colloidal Matter from Wastewater," EPA-R2-73-147; GPO (Project Officer: R. L. Bunch).

Malisch, W. R., D. E. Day, et al., "Use of Domestic Waste Glass for Urban Paving," EPA-670/2-73-038; NTIS No. PB 222 052 (Project Officer: C. A. Clemons).

Mallory, C. W., and R. Waller, "Application of Selected Industrial Engineering Techniques to Wastewater Treatment Plants," EPA-R2-73-176; GPO No. EP1.23/2:73-176; NTIS No. PB 221 144 (Project Officer: W. F. McMichael).

Martin, J. J., Jr., "Chemical Treatment of Plating Waste for Removal of Heavy Metals," EPA-R2-73-044; GPO No. EP1.23/2:73-044 (Project Officer: J. Ciancia).

Mekosh, G., and D. Ramos, "Pressure Sewer Demonstration at the Borough of Phoenixville, Pennsylvania," EPA-R2-73-270; GPO (Project Officer: J. F. Kreissl).

Miller, B. F., "Biological Conversion of Animal Wastes to Nutrients," EPA-670/2-73-009; NTIS No. PB 221 171 (Project Officer: C. A. Clemons).

Miller, E., L. Stephens, et al., "Development and Preliminary Design of a Sorbent-Oil Recovery System," EPA-R2-73-156; GPO No. EP1.23/2:73-156; NTIS No. PB 221 497 (Project Office: EWQRL Staff).

Miller, J. W., "A Multiparameter Oil Pollution Source Identification System," EPA-R2-73-221; GPO (Project Officer: B. Hornstein).

Miner, J. R., "A Recirculating Waste System for Swine Units," EPA-670/2-73-025; NTIS No. PB 221 621 (Project Officer: C. A. Clemons).

Mitchell, R. C., C. L. Hamermesh, et al., "Feasibility of Plastic Foam Plugs for Sealing Leaking Chemical Containers," EPA-R2-73-251; GPO No. EP1.23/2:73-251 (Project Officer: I. Wilder).

Mohr, D., K. McCormack, et al., "Oil Spill Surveillance System Study," EPA-R2-73-215; GPO No. EP1.23/2:73-215 (Project Office: EWQRL Staff).

Morrison, J. E., "Study of Upflow Filter for Tertiary Treatment," EPA-670/2-73-074; NTIS No. PB 223 354 (Project Officer: S. A. Hannah).

Mytelka, A. I., L. P. Cagliostro, et al., "Combined Sewer Overflow Study for the Hudson River Conference," EPA-R2-73-152; GPO No. EP1.23/2:73-152 (Project Office: EWQRL Staff).

Nebolsine, R., I. Pouschine, Jr., et al., "Ultra High Rate Filtration of Activated Sludge Plant Effluent," EPA-R2-73-222; GPO No. EP1.23/2:73-222; NTIS No. PB 221 492 (Project Officer: J. F. Kreissl).

Ohio Department of Natural Resources, "Feasibility Study of Lake Hope Mine Drainage Demonstration Project," EPA-R2-73-151; GPO No. EP1.23/2:73-151 (Project Officer: E. F. Harris).

Opferkuch, R. E., T. Ctvrtnicek, et al., "Study of Utilization and Disposal of Lime Sludges Containing Phosphates," EPA-R2-73-282; NTIS No. PB 222 354 (Project Officer: J. B. Farrell).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. I. Summary Report," EPA-670/2-73-053A; NTIS No. PB 224 580/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. II. Toxicologic Summary," EPA-670/2-73-053B; NTIS No. PB 224 581/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. III. Disposal Process Descriptions: Ultimate Incineration, and Pyrolysis Processes," EPA-670/2-73-053C; NTIS No. PB 224 582/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. IV. Disposal Process Descriptions: Biological and Miscellaneous Waste Treatment Processes," EPA-670/2-73-053D; NTIS No. PB 224 583/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. V. National Disposal Site Candidate Waste Stream Constituent Profile Reports: Pesticides and Cyanide Compounds," EPA-670/2-73-053E; NTIS No. PB 224 584/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. VI. National Disposal Site Candidate Waste Stream Constituent Profile Reports: Mercury, Arsenic, Chromium, and Cadmium Compounds," EPA-670/2-73-053F; NTIS No. PB 224 585/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. VII. National Disposal Site Candidate Waste Stream Constituent Profile Reports: Propellants, Explosives, and Chemical Warfare Materiel," EPA-670/2-73-053G; NTIS No. PB 224 586/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. VIII. National Disposal Site Candidate Waste Stream Constituent Profile Reports: Miscellaneous Inorganic and Organic Compounds," EPA-670/2-73-053H; NTIS No. PB 224 587/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. IX. National Disposal Site Candidate Waste Stream Constituent Profile Reports: Radioactive Materials," EPA-670/2-73-053I; NTIS No. PB 224 588/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. X. Industrial and Municipal Disposal Candidate Waste Stream Constituent Profile Reports: Organic Compounds," EPA-670/2-73-053J; NTIS No. PB 224 589/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XI. Industrial and Municipal Disposal Candidate Waste Stream Constituent Profile Reports: Organic Compounds (cont'd)," EPA-670/2-73-053K; NTIS No. PB 224 590/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XII. Industrial and Municipal Disposal Candidate Waste Stream Constituent Profile Reports: Inorganic Compounds," EPA-670/2-73-053L; NTIS No. PB 224 591/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XIII. Industrial and Municipal Disposal Candidate Waste Stream Constituent Profile Reports: Inorganic Compounds

(cont'd)," EPA-670/2-73-053M; NTIS No. PB 224 592/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XIV. Summary of Waste Origins, Forms, and Quantities," EPA-670/2-73-053N; NTIS No. PB 224 593/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XV. Research and Development Plans," EPA-670/2-73-053O; NTIS No. PB 224 594/AS (Project Officer: N. B. Schomaker).

Ottinger, R. S., et al., "Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste. Vol. XVI. References," EPA-670/2-73-053P; NTIS No. PB 224 595/AS; PB 224 579-SET/AS (Project Officer: N. B. Schomaker).

Parker, D. S., F. J. Zadick, et al., "Sludge Processing for Combined Physical-Chemical-Biological Sludges," EPA-R2-73-250; GPO (Project Officer: R. B. Dean).

Parkhurst, J. D., et al., "Summary Report: Pilot Plant Studies on Dewatering Primary Digested Sludge," EPA-670/2-73-043; GPO (Project Officer: R. B. Dean).

Pitt, R. E., and G. Amy, "Toxic Materials Analysis of Street Surface Contaminants," EPA-R2-73-283; GPO No. EP1.23/2:73-283 (Project Office: EWQRL Staff).

Regan, R., et al., "Cellulose Degradation in Composting," EPA-R3-73-029; NTIS No. PB 215 722 (Project Officer: C. C. Wiles).

Renn, C. E., "Management of Recycled Waste-Process Water Ponds," EPA-R2-73-223; GPO No. EP1.23/2:73-223 (Project Officer: H. Skovronek).

Roberts, A. C., "Shore Termination for Oil Spill Booms," EPA-R2-73-114; GPO No. EP1.23/2:73-114; NTIS No. PB 221 547 (Project Officer: F. J. Freestone).

Roberts, A. C., "Using Fire Streams with a Self-Propelled Oil Spill Skimmer," EPA-R2-73-181; GPO No. EP1.23/2:73-181; NTIS No. PB 221 542 (Project Officer: F. J. Freestone).

Robins, J. D., "Gas Requirements to Pressurize Abandoned Deep Mines," EPA-670/2-73-054; GPO (Project Officer: R. D. Hill).

Sack, W. A., and S. A. Phillips, "Evaluation of the Bio-Disc Treatment Process for Summer Camp Application," EPA-670/2-73-022; GPO (Project Officer: R. L. Bunch).

Sarofim, A. F., et al., "Design and Control of Incinerators, Volume I," EPA-670/2-73-089A; NTIS No. PB 223 626/AS (Project Officer: D. A. Oberacker).

Sarofim, A. F., et al., "Design and Control of Incinerators, Volume II. Appendices," EPA-670/2-73-089B; NTIS No. PB 223 626/AS (Project Officer: D. A. Oberacker).

Sartor, J. D., C. R. Foget, et al., "Oil/Sorbent Harvesting System for Use on Vessels of Opportunity," EPA-R2-73-166; GPO No. EP1.23/2:73-166; NTIS No. PB 221 550 (Project Officer: J. S. Dorrler).

Schmid, L., "Pilot Plant Demonstration of a Lime-Biological Treatment Phosphorus Removal Method," EPA-R2-73-159; GPO (Project Officer: E. F. Barth).

Schoenberger, R. J., and P. W. Purdom, "A Study of Incinerator Residue Analysis of Water Soluble Components," EPA-670/2-73-057; NTIS No. PB 222 458 (Project Officer: D. F. Bender).

Schultz, J. S., "Electrical Stimulation of Microbial Waste Treatment," EPA-R2-73-278; NTIS No. PB 222 384 (Project Officer: C. W. Chambers).

Seiler, E. L., and J. W. Altman, "Guide to the Preparation of Operational Plans for Sewage Treatment Facilities," EPA-R2-73-263; GPO (Project Officer: W. F. McMichael).

Shelley, P. E., and G. A. Kirkpatrick, "An Assessment of Automatic Sewer Flow Samplers," EPA-R2-73-261; GPO (Project Officer: R. I. Field).

Shuckrow, A. J., G. W. Dawson, et al., "Physical - Chemical Treatment of Combined and Municipal Sewage," EPA-R2-73-149; GPO No. EP1.23/2:73-149; NTIS No. PB 219 668 (Project Office: EWQRL Staff).

Smith, R., R. G. Eilers, and E. D. Hall, "Design and Simulation of Equalization Basins," EPA-670/2-73-046; NTIS No. PB 222 000.

Smith, R., "Electrical Power Consumption for Municipal Wastewater Treatment," EPA-R2-73-281; GPO No. EP1.23/2:73-281; NTIS No. PB 223 360/9WE.

Smith, R., R. G. Eilers, and E. D. Hall, "A Mathematical Model for Aerobic Digestion," EPA-670/2-73-045; NTIS No. PB 222 029.

Smith, R., R. G. Eilers, and E. D. Hall, "Mathematical Model for Post Aeration," EPA-670/2-73-044; NTIS No. PB 222 031.

"Socio-Economic Factors Affecting Demand for Municipal Collection of Household Refuse," (condensed from Decision Making and Solid Waste Disposal, University of Chicago) EPA-670/9-73-035; NTIS No. PB 225 020/7AS (Project Officer: O. W. Albrecht).

Sollo, F. W., et al., "Disinfection of Sewage Effluents," EPA-670/2-73-029; NTIS No. PB 222 355 (Project Officer: C. W. Chambers).

Stevenson, M. K., J. O. Leckie, and R. Eliassen, "Preparation and Evaluation of Activated Carbon Produced from Municipal Refuse," EPA-670/2-73-010; NTIS No. PB 221 172 (Project Officer: C. A. Clemons).

Thackston, E. L., "Secondary Waste Treatment for a Small Diversified Tannery," EPA-R2-73-209; GPO No. EP1.23/2:73-209; NTIS No. PB 221 494 (Project Officers: J. J. Westrick and J. F. Kreissl).

Thomas, D. G., R. B. Gallaher, and J. S. Johnson, Jr., "Hydrodynamic Flux Control for Waste Water Application of Hyperfiltration Systems," EPA-R2-73-228; GPO No. EP1.23/2:73-228 (Project Officer: J. M. Smith).

Vaughan, D. A., and P. D. Miller, "First Annual Progress Report on a Study of Corrosion in Municipal Incinerators," EPA-670/2-73-032; NTIS No. PB 221 851 (Project Officer: C. A. Clemons).

Weber, C. I., editor, "Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents," EPA-670/4-73-001.

Wehking, M. W., et al., "Stabilization of Sewage Solids by the Channel Aeration Process," EPA-R2-73-213; NTIS No. PB 223 134 (Project Office: AWTRL Staff).

Weinberg, M. S., H. K. Weiss, et al., "Sludge Conditioning Using SO_2 and Low Pressure for Production of Organic Feed Concentrate," EPA-670/2-73-062; NTIS No. PB 223 343 (Project Officer: R. B. Dean).

Wilmoth, R. C., "Applications of Reverse Osmosis to Acid Mine Drainage Treatment," EPA-670/2-73-100.

Wolk, R. H., and C. A. Battista, "Study of Technical and Economic Feasibility of a Hydrogenation Process for Utilization of Waste Rubber," EPA-670/2-73-066; NTIS No. PB 222 694 (Project Officer: C. C. Wiles).

Wren, E. J., "Preventing Landfill Leachate Contamination of Water," EPA-670/2-73-021; NTIS No. PB 222 468 (Project Officer: C. A. Clemons).

Wynn, C. S., B. S. Kirk, et al., "Pilot Plant for Tertiary Treatment of Wastewater with Ozone," EPA-R2-73-146; GPO No. EP1.23/2:73-146; NTIS No. PB 219 877 (Project Officer: F. L. Evans III).

Zandi, I., "Pneumo-Slurry Pipeline Collection and Removal of Municipal Solid Waste," EPA-670/2-73-072; NTIS No. PB 223 162 (Project Officer: D. A. Oberacker).

Zanoni, A. E., "Phosphorus Removal by Trickling Filter Slimes," EPA-R2-73-279; GPO (Project Officer: E. F. Barth).

Zaval, F. J., and J. D. Robins, "Water Infiltration Control to Achieve Mine Water Pollution Control – A Feasibility Study," EPA-R2-73-142; GPO No. EP1.23/2:73-142; NTIS No. PB 217 886 (Project Officer: R. B. Scott).

OTHER PERTINENT PUBLICATIONS

Analytical Quality Control Newsletter, J. B. Anderson, editor, National Environmental Research Center, Cincinnati, Analytical Quality Control Laboratory (Issued Quarterly).

Berg, G., compiler, "Viruses in Waste Renovated and Other Viruses - 1972 Literature Abstracts," EPA-6700-73-003.

Bishop, D. F., and J. M. Smith, "The EPA-DC Pilot Plant for Water Pollution Control," News of Environmental Research in Cincinnati, September 28, 1973.

Bostian, H. E., "Conserving Water at Home," News of Environmental Research in Cincinnati, November 9, 1973.

Brenner, R. C., "EPA Experiences in Oxygen-Activated Sludge," Technology Transfer Design Seminar Publication, October 1973.

Brenner, R. C., "Upgrading Trickling Filters," Technology Transfer Design Seminar Publication, November 1973.

Brugger, J. E., "CAM-1: Using Enzymes to Detect Insecticides," News of Environmental Research in Cincinnati, July 1, 1973.

Burkart, J. K., W. Moore, R. G. Hinners, and J. F. Stara, "Catalytic Converters Used in Health Effects Studies," News of Environmental Research in Cincinnati, December 28, 1973.

Carnes, R. A., "Using Reclaimed Rubber Tires in Road Dressings," News of Environmental Research in Cincinnati, October 31, 1973.

Carswell, J. K., R. W. Buelow, and J. M. Symons, "Removing Organic Matter From Drinking Water - Monitoring Treatment Processes," News of Environmental Research in Cincinnati, December 7, 1973.

Clark, R. M., and H. C. Goddard, "Relating Socio-Economic Variables to Technology for Environmental Management," News of Environmental Research in Cincinnati, August 31, 1973.

Cohen, J. M., "Physical-Chemical Processes," Technology Transfer Design Seminar Publication, August 1973.

Cohen, J. M., J. J. Westrick, and I. J. Kugelman, "Process Design Manual for Carbon Adsorption," Technology Transfer Design Seminar Publication, October 1973.

Curry, M. G., and G. M. Gigliotti, compilers, "Cycling and Control of Metals," Proceedings Environmental Resources Conference, Columbus, Ohio, October 31 - November 2, 1972. U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio, 187 pp., February 1973.

Dotson, G. K., "Constraints to Spreading Sewage Sludge on Cropland," News of Environmental Research in Cincinnati, May 31, 1973.

Interact Symposium Proceedings, University of Cincinnati - National Environmental Research Center, December 11-12, 1972, U.S. Environmental Protection Agency, National Environmental Research Center - Cincinnati, 89 pp., July 1973.

Kawahara, F. K., and E. C. Julian, "Oil Identification: State of the Art," News of Environmental Research in Cincinnati, September 14, 1973.

Kreissl, J. F., "Suspended Solids Removal," Technology Transfer Design Seminar Publication, October 1973.

Krieger, H. L., and B. Kahn, "Monitoring Radionuclides in Reactor Effluents," News of Environmental Research in Cincinnati, October 12, 1973.

Lewis, R. F., and J. M. Smith, "Upgrading Existing Lagoons," Technology Transfer Design Seminar Publication, October 1973.

Masters, H., "Using Porous Pavement to Control Runoff," News of Environmental Research in Cincinnati, August 10, 1973.

NERC-Cincinnati, "Annual Report, 1972," EPA-670/9-73-055; NTIS No. PB 222 910.

"National Environmental Information Symposium, Summary Report, Volume 1, September 24-27, 1972," U.S. Environmental Protection Agency, National Environmental Research Center - Cincinnati, 47 pp., 1973; NTIS No. PB 220 050.

Ongerth, R. H., and H. Johnson, "Consumerism and Solid Wastes," News of Environmental Research in Cincinnati, May 1, 1973.

Shultz, G. R., and D. J. Harmon, editors, "Active Research Tasks Report, Fiscal Year 1973," EPA-670/9-73-056; NTIS No. PB 223 567/AS.

Technical Information Office, "Environmental Research Publications," EPA-670/9-73-004; NTIS No. PB 223 591/AS.

Thurnau, R. C., and N. S. Ulmer, "Plastics and Incineration," News of Environmental Research in Cincinnati, July 16, 1973.

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

ADVANCED WASTE TREATMENT

February 22, 1974

ADVANCED WASTEWATER TREATMENT PLANT AT PISCATAWAY, MARYLAND

Thomas P. O'Farrell*

INTRODUCTION

The construction and operation of the Advanced Wastewater Treatment Plant at Piscataway, Md., is a joint project of the U.S. Environmental Protection Agency (EPA) and the Washington Suburban Sanitary Commission to demonstrate treatment of a secondary effluent for suspended solids, BOD, and phosphorus removal. The 5 million-gallon-per-day (mgd) ($18.9 \times 10^3 m^3$ per-day) facility was constructed at a cost of approximately $4.7 million and is presently operating under a 1-year EPA grant with a federal share of $437,258.

SECONDARY TREATMENT FACILITIES

The secondary treatment facilities at Piscataway consist of two isolated systems: an old 5-mgd, step-aeration, activated-sludge system and a new 25-mgd, step-aeration, activated-sludge system (Figure 1). The effluent from the old 5-mgd secondary system flows by gravity to the tertiary facility. A new solids-handling system (which includes thickening, vacuum filtration, and fluid solids incineration) is under construction and will have the capacity for handling the solids from a

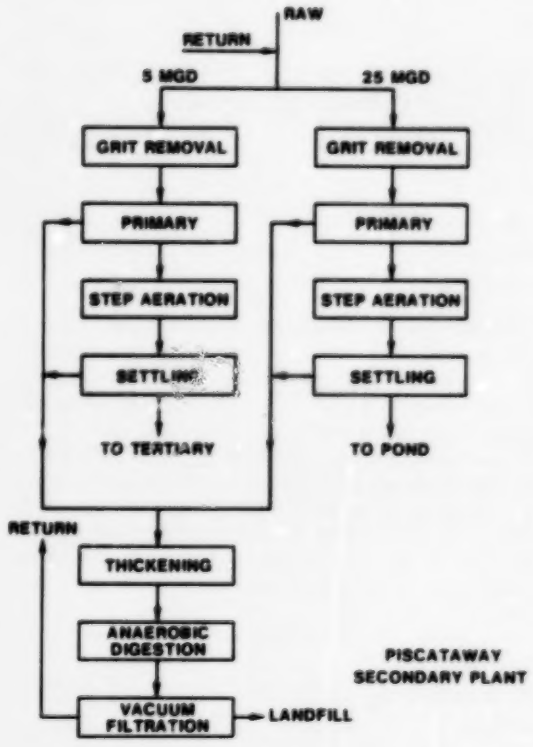

Figure 1. Secondary treatment system at Piscataway.

*Mr. O'Farrell is a Sanitary Engineer with the Advanced Waste Treatment Research Laboratory at the Blue Plains Pilot Plant, Washington, D.C. (8-900-562-6200).

30-mgd plant. The present solids-handling system has the capacity for handling the solids from a 12-mgd plant. Because of this restriction, only half of the new 25-mgd plant is in operation at an average flow of 7-mgd. Alum is added to the new aeration system for phosphorus removal.

The old secondary treatment system (Figure 1) includes grit removal with comminution, primary settling, step aeration, and secondary settling. Wasted solids from the primary and secondary settlers are combined with the wasted solids from the new activated sludge system and fed by gravity to the sludge thickener. The thickened sludge is pumped to two anaerobic digesters. Underflow solids from the digesters are dewatered by vacuum filtration and trucked to a sanitary landfill. The thickener overflow and filtrate from the vacuum filter are returned to the front of the plant ahead of the grit chambers. Under normal operating conditions, the digesters are maintained in balance and do not produce an overflow.

The effluent from the old secondary facility is of good quality (Table 1). With a mixed-liquor suspended solids of approximately 2,000 mg/l and a detention time in the aeration reactor of 4.5 hours, the system produces a nitrified or partially nitrified effluent nearly the entire year.

TABLE 1. QUALITY OF PISCATAWAY SECONDARY TREATMENT PROCESSES, mg/l

Process	BOD	SS	P	TKN	N_2+NO_2
Influent	143	182	7.8	13.7	0.3
Primary effluent	116	189	9.2	–	–
Secondary effluent	14.0	15.7	3.4	4.3	7.2

The increase in phosphorus concentration following primary settling is due to the recycling of the return flows (filtrate and thickener). The step-aeration, activated-sludge system removes approximately 50 percent of the phosphorus. The high removal of phosphorus cannot be related to the alum addition in the new plant, since the old system continually removed approximately 50 percent of the phosphorus before the construction of the new plant. A material balance of the secondary system has shown that the phosphorus removed from the effluent is accounted for in the wasted sludge.

TERTIARY TREATMENT SYSTEM

The tertiary system (Figure 2) includes two-stage lime precipitation with gravity thickening, dewatering, and recalcination; dual-media filtration; neutralization; and activated-carbon adsorption with spent-carbon regeneration. The clarifiers, recarbonation unit, and filter inlet well are located next to the operation building, which holds the remaining units and equipment (Figures 3 and 4).

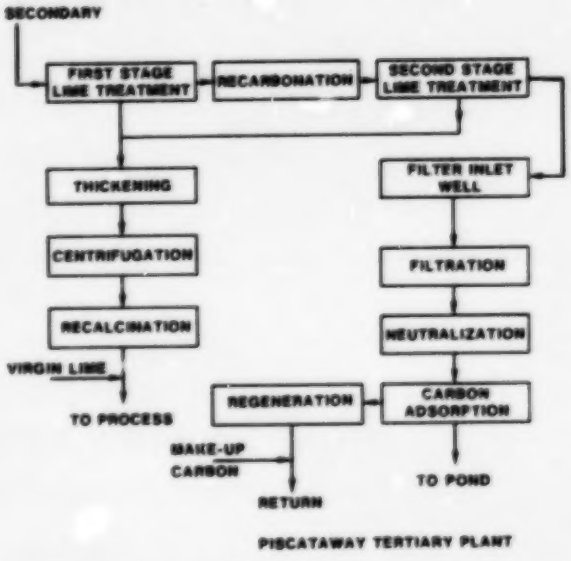

Figure 2. Piscataway tertiary plant.

The operation consists of feeding the effluent from the old step-aeration, activated-sludge system at a design flow rate of 5-mgd to the first stage clarifier. Both recalcined and virgin limes are added to the first clarifier to maintain the pH between 11.3 and 11.5 for the

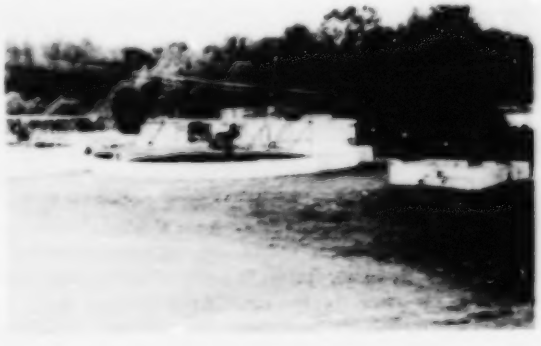

Figure 3. Tertiary plant: clarifiers, recarbonation unit, and filter inlet wall.

Figure 4. Tertiary plant: operations building.

Figure 5. Tertiary plant: carbon adsorption.

removal of phosphorus and suspended solids. Both clarification units provide internal and external recycling of solids. The effluent from the first clarifier flows by gravity to the recarbonation tank, where flue gas (8-10 percent carbon dioxide) is added to maintain the pH between 10.0 and 10.5. With the proper pH control, the excess calcium ions react with the carbon dioxide in the flue gas and are precipitated as calcium carbonate. The recarbonated effluent flows by gravity to the second-stage clarifier for settling of the precipitated calcium carbonate. Ferric chloride (20-30 mg/l $FeCl_3$) is added to the reaction zone of the second-stage clarifier as a coagulant aid.

Solids are wasted from the second clarifier to the first clarifier and from the first clarifier to the gravity thickener. The wasted sludge is thickened in excess of 20 percent solids and dewatered by solid-bowl centrifuges with the aid of polymers. The cake at approximately 40 to 50 percent solids is fed to the multiple-hearth furnace for recalcination. The centrate from the centrifuge is returned to the head of the tertiary plant. The buildup of inert solids is stabilized by the wasting of recalcined lime. The centrifugation system is able to classify the solids, thus wasting the inert solids in the centrate.

Before filtration, the pH of the clarified effluent is reduced to 8 in the filter inlet well. The liquid is then fed to five of the six dual-media filters for additional solids and phosphorus removal. The dual-media filters are backwashed on a 24-hour cycle. The filtered effluent is neutralized to pH 7 with flue gas in the stabilization tank and pumped to the carbon adsorption system. The activated carbon adsorption system (Figure 5) for the removal of soluble organic materials includes three sets of 2 columns. The effluent from the carbon adsorption system flows to a polishing pond with a residence time (at a flow of 5-mgd) of 6 days. The overflow from the pond is discharged into Piscataway Bay.

Flow to the tertiary facility was initiated in November 1972, with all unit operations placed in service in March 1973. The quality of the effluent from the tertiary system is shown in Table 2.

Because of startup delays and mechanical difficulties that have prevented continuous operation, only 42 percent of the available EPA funds were spent during the first year. A no-cost extension of the operating grant has been approved. Operation of the tertiary facility under the grant will continue until June 1974.

TABLE 2. QUALITY OF PISCATAWAY TERTIARY TREATMENT PROCESSES, mg/l

Process	TOC	COD	SS	P
Influent*	11.9	32.9	15.7	3.4
Lime clarified effluent	9.3	-	12.3	0.2
Filtered effluent	7.8	18.6	7.7	0.1
Carbon adsorption effluent	1.5	6.1	1.0	0.1

*Influent to tertiary facility is effluent from existing 5-mgd secondary system.

GLOSSARY

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TOC	Total Organic Carbon
P	Phosphorus
SS	Suspended Solids
TKN	Total Kjeldahl Nitrogen
NO_2	Nitrite
NO_3	Nitrate

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

METHODS DEVELOPMENT AND QUALITY ASSURANCE RESEARCH

March 22, 1974

IDENTIFYING ORGANIC POLLUTANTS IN WATER

J. W. Eichelberger, L. E. Harris, and W. L. Budde*

BACKGROUND

Identifying and measuring specific organic compounds that contaminate the environment has concerned environmental research scientists for many years. The huge number of potentially harmful or toxic compounds that are theoretically possible has discouraged the development of a specific analytical method for each. Instead, general approaches based on slight differences in solubility, chromatographic behavior, and spectroscopic measurements were developed and used widely to gain information about the types of compounds present in various samples.

Unfortunately, many of these standard techniques of chemistry, which provided very valuable information in flagrant pollution situations, were either slow, expensive of skilled manpower, or relatively insensitive to very small quantities. In addition, most of these techniques frequently failed to generate really definitive information. As a result, environmental researchers began to turn to a new multidisciplinary technique: computerized (automated data processing) gas chromatography/mass spectrometry (ADP/GC/MS).

This sophisticated technique was developed during the 1960's primarily to meet the demand of basic research workers in medical, biochemical, flavor, odor, medicinal, and geochemical research. Basic research supported by the National Institutes of Health, the National Science Foundation, and the National Aeronautics and Space Administration played the major role in the development of the concept. Since one of the basic problems of each of the above areas of research is the identification and measurement of trace quantities of a great variety of organic compounds, the application of the technique to environmental research was obvious but slow to come about.

*Research Chemists with the Methods Development and Quality Assurance Research Laboratory, NERC-Cincinnati (513-684-2924).

Like any automated method, ADP/GC/MS does not reduce the need for skilled manpower; in fact, it requires highly skilled, multidisciplinary teams of spectroscopists, analytical chemists, electronics engineers, and laboratory minicomputer specialists. The major advantage of this method is that it enormously increases the capacity of a fixed or limited staff to make large numbers of unambiguous identifications of specific organic compounds in environmental samples. Identification of noxious pollutants at the part-per-billion level with a high degree of confidence in the result has become nearly routine in more than a few U.S. Environmental Protection Agency (EPA) laboratories. What once was a nearly impossible task for a staff of 100 working for 6 months sometimes can be accomplished by several people in a few hours.

STATE OF THE ART

EPA has made a major commitment to ADP/GC/MS during the last few years by installing about 23 complete systems valued at about $2.5 million in laboratories across the country. The systems are employed in eight regional surveillance and analysis laboratories, both National Field Investigations Centers, two National Environmental Research Center (NERC) -- Cincinnati laboratories, one NERC-RTP laboratory, six NERC-Corvallis laboratories, and two Office of Pesticide Programs laboratories. The annual total costs dedicated to these systems should be at least equivalent to the purchase price.

System Operation

Eighteen of the systems mentioned above are nearly identical Finnigan quadrupole mass spectrometers computerized with Digital Equipment Corporation PDP-8

minicomputers* (Figure 1). The three functional parts of the systems are as follows:

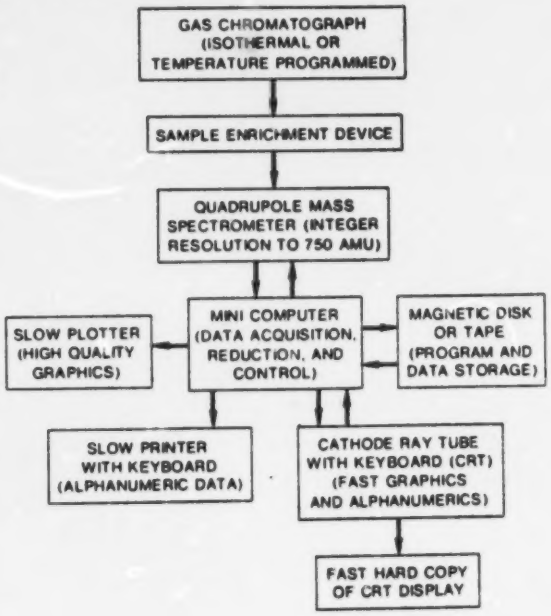
GAS CHROMATOGRAPH (ISOTHERMAL OR TEMPERATURE PROGRAMMED)
SAMPLE ENRICHMENT DEVICE
QUADRUPOLE MASS SPECTROMETER (INTEGER RESOLUTION TO 750 AMU)
SLOW PLOTTER (HIGH QUALITY GRAPHICS)
MINI COMPUTER (DATA ACQUISITION, REDUCTION, AND CONTROL)
MAGNETIC DISK OR TAPE (PROGRAM AND DATA STORAGE)
SLOW PRINTER WITH KEYBOARD (ALPHANUMERIC DATA)
CATHODE RAY TUBE WITH KEYBOARD (CRT) (FAST GRAPHICS AND ALPHANUMERICS)
FAST HARD COPY OF CRT DISPLAY

Figure 1. Configuration of the ADP/GC/MS system widely used in EPA.

(1) The gas chromatograph is very well established as a powerful tool for the separation of complex mixtures of volatile organic compounds. However, since conventional GC detectors provide too little information about the sample, they have been removed.

(2) The MS is the only GC detector used, and like conventional GC detectors, it is very sensitive. In contrast to the single-channel response of conventional GC detectors, the MS provides a multichannel response that carries a great deal of information about the molecular structure and composition of organic compounds. This information may be displayed graphically by a fast cathode-ray tube or a slow (pen + ink) plotter, printed in digital form, or transmitted over conventional voice-grade telephone circuits to other data-handling systems.

(3) The minicomputer makes the hookup possible. In noncomputerized systems, mass spectra generally are not acquired continuously during the GC run. Continuous mass spectra acquisition generates very significant information that cannot, however, be processed economically or accurately by hand. This dilemma is solved in a computerized system. Mass spectra are acquired continuously, and the minicomputer handles all this information and controls the operation of the MS simultaneously. The MS data are acquired and processed by the computer and stored temporarily on a magnetic disk or magnetic tape before plotting, printing, or transmission. Personnel who previously devoted long, unproductive hours to manual data processing are freed to do productive tasks such as data interpretation.

*Mention of commercial products does not imply endorsement by the EPA.

Methods Development and Quality Control

The Methods Development and Quality Assurance Research Laboratory (MDQARL) of NERC-Cincinnati is involved in a number of projects in ADP/GC/MS, including the development of detailed methods for use of this equipment. Of course, the manufacturers of the equipment provide basic operating instructions for the systems. But, since they manufacture equipment for use in a wide variety of applications (from cancer research to identification of drugs in racehorse urine), they cannot possibly provide detailed methods for any one of them. Methodology is needed for analytical quality control, preanalysis sample preparation, more efficient separations, special MS techniques, and data interpretation. Since ADP/GC/MS is a computerized tool, some of the methodology needed can be incorporated into minicomputer programs that can be used by well-trained operators.

Quality control techniques are of special interest, of course, to encourage the production of the valid mass spectra that are required to make correct identifications. A properly operating, well-tuned ADP/GC/MS is required to obtain a valid mass spectrum. MDQARL has developed and distributed a procedure that uses a standard reference compound to make a quick check (about 15 minutes) of the performance and proper tuning of a system. With a minimum expenditure of time, an operator using this procedure can be reasonably sure that the GC column, the sample enrichment device, all components of the MS, the data acquisition system, the data reduction system, and the data output system are all functioning properly. After an unsuccessful test, the individual subsystems must be examined and the faulty component corrected. Data acquired after a successful system check are validated and far more valuable than unvalidated data. Data acquired after an unsuccessful test may be worthless and cause erroneous identifications.

The reference compound yields fragments in its mass spectrum that are distributed fairly evenly up to mass 450. This feature allows the operator to check the low-, medium-, and high-mass range sensitivity and resolution. During the checkout procedure, the operator obtains a gas chromatogram and a mass spectrum of the reference compound. The peak in the chromatogram is observed for sharpness, size, and shape. This is a check on the GC column, sample enrichment device, and overall spec-

trometer sensitivity. The mass spectrum is compared with a list of quality criteria obtained from an inter-laboratory study and repetitive analyses. Favorable comparison indicates proper performance of the system. A supply of the reference compound is maintained for distribution as requested.

Other MDQARL Projects

Some other current projects at MDQARL include an evaluation of direct aqueous injection analyses, the use of support-coated open tubular GC columns, investigations of new packed GC columns, research on techniques for the quantitative measurement of the pollutants detected, and the development of computer programs for data interpretation.

These techniques are intended for laboratories that will use ADP/GC/MS to:

- identify organic compounds in industrial effluents for background data or enforcement action;
- characterize oil spills;
- determine organic compounds as the cause of taste and odor in drinking water supplies;
- evaluate the effectiveness of treatment systems designed to remove organic pollutants;
- study the accumulation of organic pollutants in aquatic life; and
- determine the causes of fish kills.

Direct Aqueous Injection. Direct aqueous injection analysis is the introduction of a few microliters of water sample into the ADP/GC/MS instead of an organic solvent extract. The direct analysis of water samples with GC is not a new technique, but its employment with a MS as a GC detector is new. This procedure enables the analyst to identify volatile components that are normally lost during extract concentration or components that do not extract because they are too water soluble.

The minimum detectable concentration using direct aqueous injection is 1 to 5 ppm, depending on the compound observed. Although the method is not very sensitive, it is suitable for analysis of many industrial wastes. The following compounds have been detected in some industrial waste samples using direct aqueous injection: methyl alcohol, ethyl alcohol, n-propyl alcohol, isopropyl alcohol, acetone, acetic acid, propanoic acid, butanoic acid, N,N-dimethyl formamide, 2-ethoxyethanol, 2-butoxyethanol, and methylene chloride.

Extraction with an Organic Solvent. Many types of compounds have been detected in industrial waste samples by extracting them with an organic solvent, such as methylene chloride, concentrating them into a very small volume, and injecting a small portion into the ADP/GC/MS. The sensitivity is greatly increased with the extraction procedure, and as little as 0.1 ppb of a compound can be detected in a liter of water. The following list, though by no means complete, does name some of the most interesting compounds detected in industrial wastes by solvent extraction: N-methylcarbazole, t-butylanisole, benzonitrile, trichlorophenol, fluorene, pyrene, indole, naphthol, alpha terpineol, o-phenylphenol, pentachlorophenol, and methylnapthalene.

Interpretation of Data

The necessary prerequisite of effective data interpretation in ADP/GC/MS is the availability of valid mass spectra. Assuming that the ADP/GC/MS is well tuned and in good operating condition, the only other requirement for valid mass spectra is the clean separation of the individual components of a mixture on the GC column. This is, of course, the classical problem of chromatography, but it is made somewhat more manageable with the MS detector. An experienced user can frequently ascertain that the separation is clean and free of overlaps by an examination of the internal consistency of the MS data. This is not possible with the simpler, conventional GC detector.

There are two fundamentally different approaches to the identification of specific organic compound pollutants from valid mass spectra. Interpretations may be attempted based on the theory of mass spectra and the rules of fragmentation of organic ions in the gas phase. Unfortunately, this approach is frequently slow and tedious and requires Ph.D-level training or experience. However, it is generally far more definitive than the equivalent approach with other types of spectrometry (e.g., infrared spectra). This approach is clearly justified when all else fails in important situations such as an enforcement action or fish kill.

The alternative is the purely empirical method of searching a file of reference mass spectra to find a similar or exact match of the experimental spectrum. Manual searching of printed data is rather slow, subject to human error, and intellectually unstimulating. Computerized searches overcome these problems, and two experimental remote systems are in use by EPA. The two systems are markedly different in their approach to the problem and both are described briefly. Perhaps the simplest approach would be to utilize the PDP-8 minicomputer and disk or tape available on the MS data system to search a data base of reference spectra. This may be the most economical method, but it has not been developed fully and is not currently used by EPA.

One system used by EPA was developed by the Battelle Memorial Institute with funding from the Southeast Environmental Research Laboratory component of NERC-Corvallis. It is intended to be used by a laboratory technician who needs to know the correct buttons to operate and the correct commands to enter. MS data are transmitted in batches directly from the ADP/GC/MS data system to a large Control Data

Corporation model 6400 computer at Battelle-Columbus via standard voice-grade telephone lines. The system is highly automated, rather sophisticated, and makes good use of the data. It is simple to use because it either finds a match or it doesn't, and if it doesn't, there are no other alternative modes of search. The system does require the ADP/GC/MS data system, and ADP/GC/MS is precluded during its use.

The other system used by EPA was developed by the National Institutes of Health (NIH) and may be used by any EPA laboratory under an existing EPA-NIH interagency agreement. This system runs on a large Digital Equipment Corporation model PDP-10 computer at the NIH computer center in Bethesda, Maryland. The user enters MS data via a standard keyboard/printer terminal connected to a standard voice-grade telephone line and does not utilize the resources of the ADP/GC/MS data system. The matching system is highly interactive and conversational, and the user must impose his judgment in entering data. This system is oriented to the experienced user who sits in the interactive loop with the computer program and has many optional approaches to probing the data base and searching for a match. This approach makes less efficient use of computer resources and depends more on an operator's judgment to make good use of available data. However, it is a more flexible method, especially when an exact match is not available. For economy and additional flexibility, these two experimental systems will probably be combined with the same data base on the same time sharing computer in the near future.

EPA-MS USERS GROUP

In the spring of 1972, MDQARL organized an EPA-MS users group. The purpose of the group is to promote the informal exchange of technical information among the EPA laboratories using the 23 computerized GC/MS systems. The group is designed to be especially helpful to laboratory personnel (e.g., regional surveillance and analysis chemists) who are just beginning to acquire the skills necessary to utilize this sophisticated equipment effectively. In addition, the group keeps all involved personnel up-to-date on the latest instrumental improvements, new techniques, new equipment additions, and new software programs and capabilities.

CONCLUSION

It has been clearly demonstrated that ADP/GC/MS can provide extremely high quality and highly significant information about organic environmental pollutants to environmental scientists and enforcement officials. However, the achievement of this capability requires a substantial laboratory management commitment.

The ADP/GC/MS is not the kind of equipment that can stand idle for weeks and then be used effectively by occasional users. Users require in-depth knowledge, and the equipment requires routine maintenance, adjustment, and utilization. Furthermore, the commercial packages are not perfected and will require updating in the future. Nevertheless, we deeply believe that the commitment is worth it and that ADP/GC/MS routine analyses should replace, in many EPA laboratories, some of the traditional water pollution methodology that generates less relevant and very much less significant data.

WATER POLLUTION CONTROL TECHNOLOGY ASSESSMENT
An Environmental Resources Conference, May 1-3, Columbus, Ohio

The sessions, cosponsored by the U.S. Environmental Protection Agency and Battelle's Columbus Laboratories, will be held in the Battelle auditorium. Additional information may be obtained from either G. R. Smithson, Jr. (program) or D. A. Yothers (arrangements) at Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201; telephone (614) 299-3151. Registration fee for the conference is $60.

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U S ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

SOLID AND HAZARDOUS WASTE RESEARCH

April 12, 1974

SURVIVAL OF FECAL COLIFORMS AND FECAL STREPTOCOCCI IN A SANITARY LANDFILL

Janet C. Blannon and Mirdza L. Peterson*

BACKGROUND

Today, land disposal is the method widely used for disposing of municipal solid waste. According to the 1968 National Solid Waste Survey,[1] only 6 percent of all landfill operations in the United States could be classified as sanitary landfills; the remaining 94 percent were unacceptable and represented disease potential, threat of pollution, and land blight.

Recent studies have shown that 1g of raw residential solid waste contains 1 million or more fecal coliforms and fecal streptococci, and it may harbor salmonellae, enteroviruses, and pathogenic fungi as well.[2-4] A major concern has been whether or not the sanitary landfill method of solid waste disposal permits pathogenic microorganisms to survive and be transmitted into the environment through the leaching processes. Because only limited information is available on the microbiologic quality of landfill leachates, a study was conducted to determine the occurrence and survival of fecal coliform and fecal streptococcus organisms in leachates collected from an experimental, field-scale sanitary landfill during an 11-month leaching period. A characterization of fecal streptococcus types and an evaluation of fecal coliform to fecal streptococcus ratios were used as criteria for determining whether the source of pollution was human or nonhuman warm-blooded animals.

*Mrs. Blannon is Laboratory Technician, Water Supply Research Laboratory, U.S. Environmental Protection Agency, National Environmental Research Center - Cincinnati, Ohio.

Dr. Peterson is Senior Research Microbiologist, U.S. Environmental Protection Agency, National Environmental Research Center, Research Triangle Park, North Carolina.

MATERIALS AND METHODS

Experimental Landfill

The landfill, which was a trench-type operation, was 149 ft. long by approximately 30 ft. wide. The trench was excavated, with two vertical sidewalls and two ramps (one for entrance and one for exit), sloping approximately 1 ft. vertically to 7 ft. horizontally. The landfill contained 435 tons (wet weight) of residential solid waste compacted to 1,035 lb. per cu. yd. (wet weight). A D-7 crawler tractor was used for compaction.

Sampling. The first leachate occurred approximately 6 weeks after placement of the landfill. Leachates were collected weekly in 1,000-ml sterile bottles from the upper pipe, which lay directly under the compacted solid waste, and from the lower pipe, which was located beneath an 18-in. clay soil liner (Figure 1).

Laboratory Technique

Total and fecal coliforms and fecal streptococci were estimated by the most probable number (MPN) method,[5] using the five-tube technique. Fecal streptococci were characterized by a method described in an Environmental Protection Agency (EPA) training manual.[6]

RESULTS AND DISCUSSION

The average densities of fecal coliforms and fecal streptococci in leachates collected from the upper pipe during the 11-month sampling period are depicted in Figure 2. During the initial 2-month leaching period, the fecal coliform and fecal streptococci densities averaged 1.5 million and 48 million organisms per 100 ml, respectively. Beginning

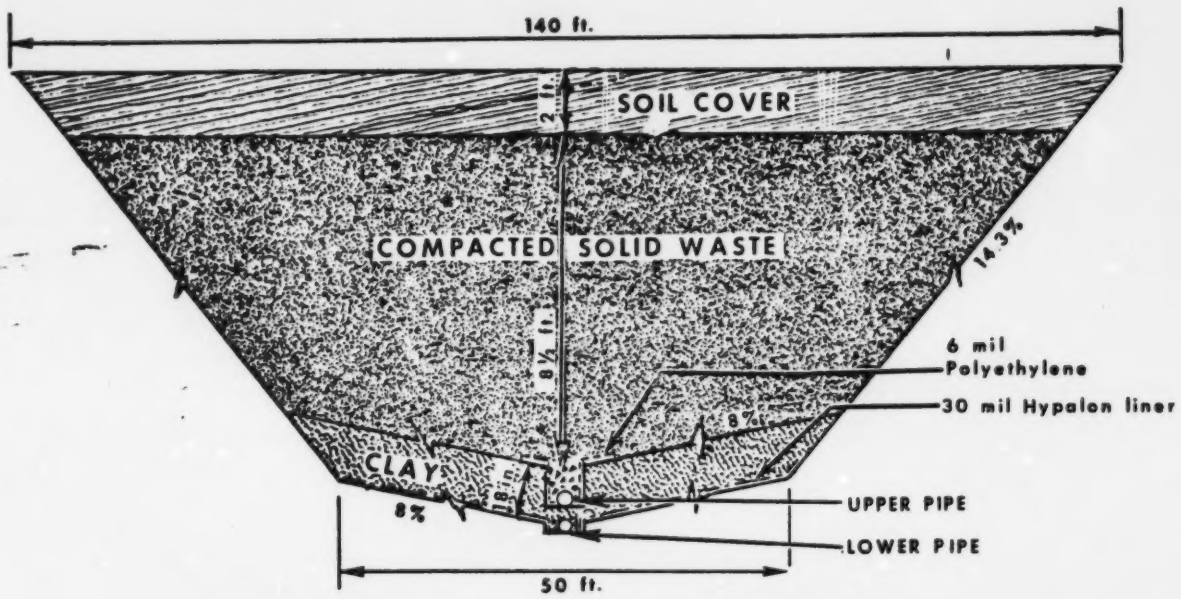

Figure 1. Cross section of collection system for landfill leachates.

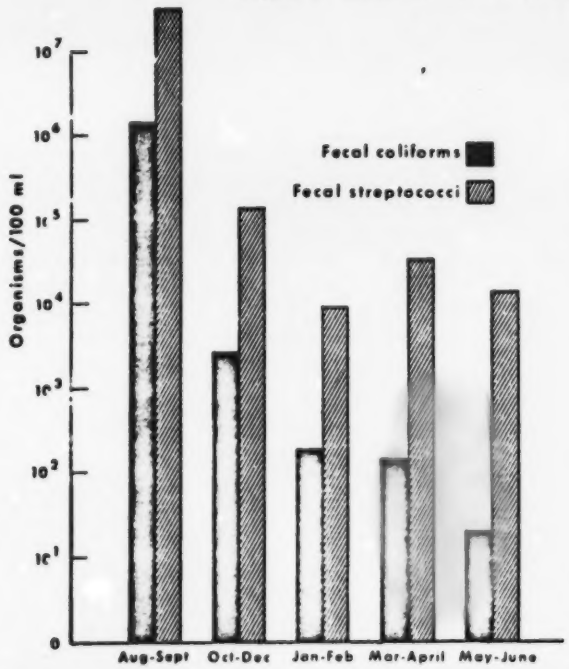

Figure 2. Average densities of fecal coliforms and fecal streptococci in leachates from the upper pipe.

with the third month of the study, the fecal coliform density dropped sharply and remained at low values, ranging from 30 to 180 organisms per 100 ml, for the last 6 months of the study period. In contrast, fecal streptococci exceeding 10,000 organisms per 100 ml were leached during the final sampling period.

Temperature measurements during the first week of the test ranged from 120 to 140 F (48.8 to 60 C) in the middle section of the landfill (2- to 6-ft. depths) and were 10 to 15 degrees lower in the periphery. After the first week, temperatures in all sections of the fill underwent a gradual decline and reached a range of 50 to 60 F at the end of 11 months. Organisms that occurred in leachates from the upper pipe are believed to have been leached from the peripheral or surface areas of the landfilled solid waste masses that were subjected to lower temperatures.

In leachates from the lower pipe, the average fecal coliform and fecal streptococci densities for the first 2-month survey period were 280,000 and 460,000 organisms per 100 ml, respectively (Figure 3). Fecal coliform values soon dropped to 20 organisms per 100 ml and remained consistent over the last 2-month survey period. Fecal streptococci averaging 2,900 organisms per ml were, however, leached from the lower pipe at the end of the 11-month sampling period.

The relatively large numbers of fecal organisms in leachates from the lower pipe indicated insufficient filtering action from the 18-in. clay soil liner under the compacted waste.

Biochemical characterization and percentage occurrence of fecal streptococcus strains in each leachate sample collected during the last 2-month

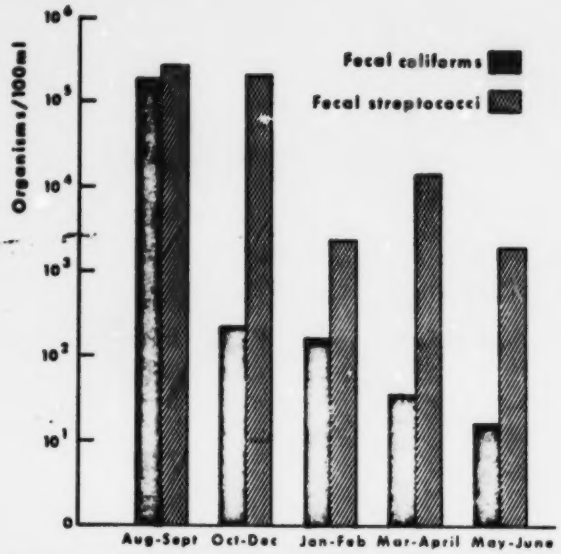

Figure 3. Average densities of fecal coliforms and fecal streptococci in leachates from the lower pipe.

survey are shown in Tables 1 and 2. A total of 60 streptococcus strains isolated from leachates were examined and characterized. Of these, 35 (58.3%) were strains of *Streptococcus faecalis* var. *liquefaciens,* which are ubiquitous in the environment, and 5 (8.33%) were atypical strains of *S. faecalis* that have been found in association with vegetation. Thus, 66.7 percent of the streptococci isolated from leachates during the last 2 months had no sanitary significance. The remaining 33.3 percent, which included *S. faecalis* biotypes II and III (12 strains), *S. durans* (3 strains), and *S. equinus* (5 strains), were indicative of fecal contamination from warm-blooded animals.

Fecal coliform to fecal streptococcus ratios (FC/FS), determined in each leachate sample during the initial 5-week leaching period, ranged from 0.011 to 6.202 (Table 3). Studies by Geldreich and Kenner[2] have shown that in human fecal material and in domestic wastewater, the fecal coliform densities exceed those of fecal streptococci by a factor of four to one or greater, whereas, a complete reversal of the fecal coliform to fecal streptococcus ratio (less than 0.07) is seen in fecal discharges from livestock or poultry wastes and in storm waters. Thus, the use of fecal coliform to fecal streptococci ratios in leachate studies detected fecal contamination of leachate derived from human and animal origins and suggested that the microbiologic quality of leachates may be compared with that of storm water runoff and raw domestic wastewater. The fecal coliform to fecal streptococci ratios must be applied carefully, however, since these correlations may be altered because of the various ecological factors existing in solid waste landfills. This possibility was illustrated in part by the rapid die-off of fecal coliforms and by the survival of fecal streptococci. Thus, the use of a ratio relationship for leachates may be valid only during the initial leaching period. The fecal streptococcus system, including types characterization,

TABLE 2.
OCCURRENCE OF STREPTOCOCCI IN LEACHATES*

Species	% Occurrence
S. faecalis var. *liquefaciens*	58.33
S. faecalis biotype II	15.00
Atypical *S. faecalis* var.	8.33
S. faecalis biotype III	5.00
S. durans	5.00
S. equinus	8.33

*Analyses of 60 cultures

TABLE 1. BIOCHEMICAL REACTIONS OF STREPTOCOCCI ISOLATED FROM LEACHATE*

No. of strains	Growth @		Growth in		Reduction of		Hydrolysis of Starch	Litmus Milk				Species
	10C	45C	6.5% NaCl	pH 9.6	Methylene Blue	K_2TeO_3		Acid	Coag.	Reduct	Pepton	
35	+	+	+	+	+	+	−	+	+	+	+	*S. faecalis* var. *liquefaciens*
9	+	+	+	−	+	+	−	+	+	+	−	*S. faecalis* biotype II
5	+	+	+	+	+	+	+	+	+	+	+	Atypical *S. faecalis* var.
3	+	+	−	+	+	−	−	+	+	+	−	*S. faecalis* biotype III
3	+	+	+	+	+	−	−	+	+	+	−	*S. durans*
5	−	+	−	−	−	−	+	−	−	−	−	*S. equinus*

*All strains grew in 40% bile

TABLE 3. DISTRIBUTION OF FECAL COLIFORMS AND FECAL STREPTOCOCCI IN LEACHATES FROM THE UPPER PIPE

Collection Date	Densities/100ml		Ratio
	Fecal coliforms	Fecal streptococci	FC/FS
8-31-71	2.6×10^{4}	2.4×10^{8}	0.011
9-1-71	4.9×10^{4}	7.9×10^{5}	6.202
9-13-71	2×10^{3}	7.9×10^{4}	0.025
9-20-71	9×10^{3}	3.3×10^{4}	0.272
9-27-71	3.3×10^{4}	1.70×10^{5}	0.194

should therefore be used in addition to the fecal coliform system to identify the origin of leachate pollution.

This study has shown that leachate contamination, if not controlled, may pollute the soil, recreational waters, and groundwater and may pose hazards to the public health. The study also demonstrated the poor filtering action of the 18-in. clay soil liner under the compacted solid waste.

SUMMARY

Leachates discharged from sanitary landfills during the initial 2-month leaching period (2 to 4 months after the placement of the cell) contain high densities of fecal coliforms and fecal streptococci of human origin and should be considered potential sources of pathogenic microorganisms. Continuous microbiologic monitoring of leachate quality based on the detection of fecal pollution sources is indicated.

REFERENCES

1. Black, R. J., Muhich, A. J., Klee, A. J., Hickman, H. L., Jr., and Vaughan, R. D., "The National Solid Waste Survey; An Interim Report." U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, 1968.

2. Peterson, M. L., "Pathogens Associated with Solid Waste Processing." Open-file report (out of print), U.S. Environmental Protection Agency, Cincinnati, Ohio, 1971.

3. Spino, D. F., "Bacteriological Study of the New Orleans East Incinerator." Open-file report (out of print), U.S. Environmental Protection Agency, Cincinnati, Ohio, 1971.

4. Gaby, W. L., "Evaluation of Health Hazards Associated with Solid Waste Sewage Sludge Mixtures." U.S. Environmental Protection Agency, National Environmental Research Center – Cincinnati, Ohio, 1974.

5. "Standard Methods for the Examination of Water and Wastewater." American Public Health Association, Washington, D.C., 1971.

6. Kenner, B. A., and Haley, P. C., *In* "Current Practices in Water Microbiology." U.S. Environmental Protection Agency, Office of Water Programs, Cincinnati, Ohio, January 1973.

7. Geldreich, E. E., and Kenner, B. A., "Concepts of Fecal Streptococci in Stream Pollution." JWPCF, 4, R336-R352, 1969.

☆ U.S. GOVERNMENT PRINTING OFFICE 1974— 748-494/1186

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U S ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

ADVANCED WASTE TREATMENT

May 3, 1974

SLUDGE INCINERATION AND FUEL CONSERVATION

R. A. Olexsey and J. B. Farrell*

BACKGROUND

Disposal of municipal sewage sludge by incineration is a relatively new practice. Until 1935, no sludge incineration was practiced in the United States,[1] but by 1972, the United States was incinerating 2,750 dry tons of sludge per day, or 25 percent of total raw sludge generation (4.2 million tons per year).[2] The use of incineration as a disposal technique is rapidly increasing, as shown by installation figures for the United States from four major manufacturers:[3]

Year	*No. of units installed*
1963	18
1964	16
1965	20
1966	10
1967	24
1968	28
1969	27
1970	26
1971	44

New sludge incinerator installations are expected to average 70 units per year in the 1970's.[4]

Incineration is generally more costly than alternative methods such as sanitary landfill or landspreading. However, these alternative methods require large land areas if offensive conditions are to be avoided. Increased cost and reduced availability of land near urban wastewater treatment facilities have created the trend toward incineration, which provides a sanitary method for disposal of sludge in a relatively small land area.

Unfortunately, the fuel shortage has cast a new shadow on sludge disposal by incineration. The steadily increasing cost and decreasing availability of gas and oil will affect the sludge disposal options of authorities, at least in an economic sense, since sludge in its liquid form contains far too much water to permit economical incineration.

When the sludge solids content can be increased by dewatering to approximately 30 percent, it is autocombustible; that is, the heat of combustion of the solids in the sludge generates sufficient heat to evaporate excess water, reach combustion temperature, and compensate for heat losses in the flue gas and through the incinerator walls.† Generally, sludge cakes below this solids content will require introduction of auxiliary fuel into the combustion chamber to provide sufficient heat to reach the required combustion temperature. Of course, auxiliary fuel requirements will vary with sludge volatile content, presence of incombustible chemicals, heat loss from the incinerator, and excess air usage.

AUXILIARY FUEL REQUIREMENTS

Table 1 presents the data on auxiliary fuel consumption for sludge incineration in seven cities. For lack of better data, let us call these cities "typical" and extrapolate consumption data across the United States. The weighted average consumption for the seven cities listed in Table 1 is 51.6 gal per ton. If this figure is rounded to 50 gal per ton nationwide, it yields a ballpark figure of 135,000 gal per day, or over 50 million gal per year of No. 2 oil (or its equivalent‡) for sludge incineration based on the 1972 sludge incineration data.

Projected figures for the future are expected to increase dramatically. As cities expand their facilities to accommodate secondary and tertiary treatment, greater volumes of sludges with higher moisture levels and greater chemical contents are being produced. Minneapolis – St. Paul, for example, is expanding its treatment facility to process only 33 percent more sewage by 1976, but it expects to be consuming 330 percent more fuel, an increase from 4.5 to 14.9 million gal per year.[5] Ample evidence indicates that improved treatment facilities will soon be producing a sludge that requires approximately 100 gal of fuel to combust 1 ton

* Mr. Olexsey (Mechanical Engineer) and Dr. Farrell (Acting Chief) are both with the Ultimate Disposal Section of the Advanced Waste Treatment Research Laboratory, National Environmental Research Center – Cincinnati (513-684-8268).

† A 50/50 mixture of primary and secondary sludge with 64 percent volatile solids produces 9,500 Btu/lb heat of combustion for dry volatile solids, 10 percent by weight CaO, 2.5 percent $FeCl_3$, and 75 percent excess air for a multiple hearth furnace with exhaust gas temperatures of 800°F.

‡ If natural gas was used, it was converted to an amount of oil that would yield an "equivalent" amount of heat.

TABLE 1. AUXILIARY FUEL CONSUMPTION FOR SLUDGE INCINERATION IN CITIES DURING 1972*

City†	Sludge generation (dry tons/day)	Percent solids‡	Daily fuel consumption§	Fuel/ton dry solids§
Jersey City, N.J.	15	30 (P)	360	28
Providence, R.I.	30	25 (PS)	850	28
Tonawanda, N.Y. (G)	6	25 (P)	100	17
Rochester, N.Y. (B)	17	30 (P)	715	42
Hartford, Conn. (GS)	25	15 (PS)	4,000	160
St. Louis, Mo. (Lemay) (G)	55	30 (P)	1,200	22
St. Paul, Minn.	275	20 (PS)	12,000	45

* Figures were obtained by telephone from plant operators.
† G = city uses natural gas; fuel figures are Btu equivalents.
GS = city uses oil in winter and natural gas in summer.
B = oil figure includes fuel for boiler in building.
‡ P = primary only.
PS = primary and secondary.
§ In gallons of No. 2 oil or the equivalent (if natural gas was used, it was converted into an amount of oil that would yield an "equivalent" amount of heat).

of sludge, assuming that current techniques are employed.

Clearly, unless there are modifications or improvements in the technology, the trend toward sludge incineration will be at variance with the fuel conservation goals of the Nation. However, many cities have no feasible alternatives to incineration.

FUEL AVAILABILITY PROSPECTS: SHORT AND LONG TERM

In the coming months, the availability of fuel for sludge incineration will vary indirectly with geography. Cities on the east coast that depend on fuel oil will face the most uncertainty.

Cities in the Midwest that use natural gas do not expect any problems, and some have even obtained uninterruptible contracts with suppliers. Some midwestern cities that use fuel oil are in the same situation as their counterparts on the east coast. However, natural gas usage is much more prevalent in the Midwest.

In the Western States, incineration is much less common since land is much more available. The cities contacted that are incinerating do not report problems in fuel availability.

In the long run, it can be expected that cities will be forced to seek either alternatives to the current fuel consumption practices or to the incineration process itself. The prospects for Minneapolis – St. Paul, whose predicted future needs are 14.9 million gal, or Washington, D.C., whose needs are 22 million gal, must be considered poor.[6]

Incineration requires an extremely heavy capital investment, which cities amortize over a number of years. A decision made in the recent past to install incinerators cannot be reversed without enormous loss of capital.

Two basic considerations must be faced: what to do in the long run to implement incineration technologies that will be less fuel dependent, and what to do in the emergency situations that can be expected in the near term.

OPTIONS FOR THE FUTURE

Curiously, it is easier to develop long-term strategies than it is to solve temporary "crisis" situations. Long-term problems permit the luxury of planning for expected circumstances. In an imminent "crisis," the unknown factor inhibits modeling and design.

Perhaps the best potential method is the incineration of solid waste along with sewage sludge. Refuse as an auxiliary fuel has much going for it. It is a universal commodity found in all communities at generation rates proportional to those of sewage sludge. Refuse is a low-sulfur fuel with a heat content sufficient to provide the necessary heat energy to combust sludge. The same circumstances that tend to push communities toward incineration of sludge also work in favor of refuse incineration, so that the two are most often practiced in parallel. It would seem logical if the two disposal operations were performed concurrently, either in a refuse combustor, a sludge incinerator, or some hybrid unit.

Coal offers the advantage of abundant supply and the prospect of serving as an aid to dewatering. However, use of the most readily available high-sulfur coal would depend on the ability of air pollution control equipment to remove sulfur oxides from the exhaust gases. Fortunately, well designed and maintained wet scrubbers used to control particulate emissions have demonstrated the capability to capture over 90 percent of the sulfur dioxide in flue gases.

Paradoxically, heat treatment of sludge, which requires heat energy, can conserve fuel. Heat-treated sludge dewaters to a high solids content. Excess heat created when this high-solids cake is incinerated can be used to provide the heat energy required for the heat treatment. This scheme is not without its drawbacks, because process complexity is increased and substances dissolved during the heat treatment increase the biological load on the treatment plant.

On the horizon now are new dewatering processes that may be capable of producing a cake that is autocombustible. Mechanical presses and pressure filters capable of delivering cakes in excess of 50 percent solids are in various stages of development.

Other alternatives would appear to be an improved wet oxidation process and the extensive use of countercurrent heat exchangers in incinerators. Also, new combustion techniques such as starved-air incineration may yield a more fuel-efficient operation.

CONTINGENCY MEASURES

Some cities may possibly run out of fuel for periods of time. These "spot" shortages will most likely result from queuing of allocations and should be of limited duration. Such shortages will most likely occur near the ends of months if cities are forced to survive on monthly

allocations that are some percentage of a previous year's consumption. Although no specific rulings are on record, the Federal Energy Office allocations provide "sanitation services" with all the fuel they require. Sewage treatment plants should not be lacking if there is oil available. Those shortages that might occur will represent a challenge to plant operators. If the quality of sewage treatment is not to suffer, provisions must be made for coping with or preventing dry-tank situations.

GETTING BY WITH LESS

There are a number of belt-tightening methods that could be employed to reduce fuel consumption and to stretch dwindling allocations:

1. Thermal losses that are due to temperature cycling could be reduced. Thermal losses from shutdown and restart of a multiple-hearth incinerator can account for as much as 15 percent of the total heat loss and as much as 80 percent of the auxiliary fuel demand.[7] Therefore, the largest and easiest reduction in consumption can be obtained by eliminating much of the startup-shutdown procedure by adopting multiple-shift, 24-hr per day operation wherever possible.

Since many cities have oversized incinerators that only operate a few days a week, storage capacity for the raw or thickened sludge is required. Cities that have recently converted from digestion to incineration could utilize abandoned digesters for liquid sludge storage. Incinerators could be allowed to cool down completely between burnings. Then, when the storage capacity is exhausted, the dewatering equipment and incinerator(s) could be operated continuously until the inventory of sludge is consumed.

2. The solids content yield of the dewatering equipment could be increased. As stated earlier, sludge is autothermic at approximately 30 percent solids. However, below 30 percent solids there is an incremental reduction in auxiliary fuel demand for every incremental increase in solids content of the feed. "Fine tuning" the operating conditions of the dewatering equipment can increase the solids content of the sludge cake.

Vacuum filters, the most common dewatering device, will yield a drier cake through more careful control of the types and quantities of conditioning agents. When the conditioning agents are inorganic chemicals such as lime or ferric chloride, however, auxiliary fuel reduction does not follow a one-to-one correspondence with any reduction in moisture content, since the chemical addition decreases the volatile content of the sludge cake.

The vacuum filter operating conditions can be adjusted to the benefit of fuel conservation. A drier cake is achieved if the rotational speed is reduced or if the liquid level in the sludge pan is lowered. Centrifuges will yield a drier cake if throughput rates are reduced.

Before feeding the vacuum filter, a thickening step would be useful. Filter yield is approximately proportional to the solids content of the input sludge. If the sludge is thickened, it will be possible to slow the filter down and achieve the same yield, but with a drier cake.

3. Combustion of skimmings and/or waste crankcase oil could be considered. Most cities no longer incinerate plant skimmings because of the difficulties in handling this material. Nevertheless, this material is of high fuel value because of its grease content (see Table 2), and addition to the sludge cake should be considered.

Sewage treatment plants may be able to purchase waste oil that has been collected from automotive service stations. Since the imposition of a 6-cent per gallon tax on re-refined lubricating oil in 1965, the market for this commodity has diminished substantially.[11] However, there is currently a 25 percent shortfall of lubricating oil crudes that could reduce the availability of this fuel. Used lubricating oil contains high levels of lead and other metals so efficient wet scrubbers will be necessary to reduce particulate emissions to acceptable levels.

4. Digester methane could be used as fuel. Many plants that have converted to incineration retained their digesters and have continued to digest sludges. In many cases, the digester gas is simply discarded or flared. As supplemental fuel becomes increasingly expensive and less available, greater efforts should be made to constructively utilize this wasted fuel.

If it is not practical to utilize the digester gas as an incinerator fuel, consideration should be given to eliminating the digestion operation. Although digestion reduces sludge mass and may even aid dewatering, it reduces the volatile content of the sludge to an extent that the heating value suffers.[12] Digested sludge must be brought to a much higher solids content than raw sludge for autothermic incineration.

WHEN THE TANKS ARE DRY

Unavoidably, some cities may not have oil for short periods of time. This situation will present less of a burden if a plan of action is developed in advance.

Covered storage, of course, is the least disruptive interim measure. Here, the old digester is ideally suited. If the period of shortage exceeds the storage capacity,

TABLE 2. COMPARATIVE HEATING VALUES OF PERTINENT FUELS[9,10]

Fuel	Heating value (Btu/lb)	Ratio of fuel values to value for No. 2 oil
No. 2 oil	19,600	1.00
No. 6 oil	17,500	0.89
Natural gas	22,800	1.16
Bituminous coal	13,600	0.69
Wood (air dried)	5,500	0.28
Grease and scum	16,700	0.85
Sludge (dry volatiles)	10,000	0.52
Digested sludge	5,300	0.27
Digester gas (60%)	15,400	0.79
Municipal refuse (20% moisture)	4,900	0.25

the digester could be utilized for digesting. The sludge could be dewatered and then disposed of at the sanitary landfill where the incinerator ash is normally taken. If there is no old anaerobic digestion facility, the sludge could be aerobically digested.

Liquid sludge can be treated with lime to pH 12 while under agitation with air. This process will remove the ammonia odor and kill pathogens if held for 2 hr. The lime-conditioned sludge will dewater well and can then be disposed of at a sanitary landfill. The sludge should not merely be piled in the open air, as odors will eventually develop.

In areas where temporary air pollution code variances may be obtained because of fuel shortages, high-sulfur coal is an option, but not a long-term solution. Wet scrubbing is necessary to maximize SO_2 removal.

If a sensible approach is taken and contingency measures are designed before emergency situations arise, the fuel crisis need not lead to a water quality crisis and an undoing of much of the progress that has been won.

REFERENCES AND FOOTNOTES

1. Groen, M. A. "Sludge Drying and Incineration at Dearborn, Michigan." Sewage and Industrial Wastes, 31:1432-1434, December 1959.

2. U.S. Environmental Protection Agency, Municipal Pollution Control Division, Office of Environmental Engineering. "Program Review, July 17, 1973." Washington, D. C. 20460. pp. 6-7.

3. Installation lists were provided by four major manufacturers of sludge and incineration equipment.

4. U.S. Environmental Protection Agency, Office of Air and Water Programs. "Background Information for Proposed New Source Performance Standards," Vol. 1. APTD-1352a. June 1973. Research Triangle Park, North Carolina 27711. p. 60.

5. Source: Metropolitan Sewer Board of the Twin Cities area.

6. Estimate for 1976. Source: District of Columbia Bureau of Wastewater Treatment.

7. Smith, Robert. "Incineration of Organic Sludges." NERC-C in-house memorandum, September 17, 1972, National Environmental Research Center, Cincinnati, Ohio 45268.

8. Perry, J. H., ed. "Chemical Engineer's Handbook." 4th ed. 1963. McGraw-Hill, New York.

9. Burd, R. S. "A Study of Sludge Handling and Disposal." Publ. WP-20-4. May 1968. U.S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio 45268.

10. Kaiser, E. General discussion of "Characteristics of Municipal Refuse" by J. M. Bell. In: Proc., National Conference on Solid Waste Research, American Public Works Association Research Foundation, December 1973. p. 37.

11. "Re-refining: Processes Avoid Polluting." Chemical and Engineering News, 49:9, October 11, 1971.

12. Owen, M. B. "Sludge Incineration." Proc. ASCE, J. Sanitary Engineering Division, Proc. Paper No. 1172, February 1957.

☆ U.S. GOVERNMENT PRINTING OFFICE 1974—758-494/1193

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U S ENVIRONMENTAL PROTECTION AGENCY
EPA 335

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

SOLID AND HAZARDOUS WASTE RESEARCH

June 7, 1974

PRODUCING PROTEIN WHILE REDUCING WASTE

Charles J. Rogers*

BACKGROUND

Justifying the development of products that would vie for a place in the subsidized farm market was quite difficult in 1968 because of the low prices of agriculturally grown protein sources (corn, soybeans, wheat, etc.). Nevertheless, studies in this area were supported by the U.S. Environmental Protection Agency (EPA), and the wisdom of that decision has paved the way for what we view as essential immediate and futuristic technology.

Billions of tons of cellulose occur annually in agricultural and municipal waste streams, and an economically feasible technology is needed to cope with it. To this end, the EPA, through the Solid and Hazardous Waste Research Laboratory (SHWRL) of the National Environmental Research Center, Cincinnati, supports contracts, grants, and in-house studies directed to recycling some of this hugh tonnage of cellulose. Considerable research emphasis has been placed on the digestion of cellulose by microbes to produce protein, the fabrication of microbial proteins into commercially valuable products, and the hydrolysis of cellulose to yield glucose for use in the production of ethyl alcohol.

OPTIONS FOR REUSING CELLULOSE

Novel and diverse methods are being developed to utilize the vast quantities of cellulosic material accumulating as waste products from activities such as food processing, lumbering, papermaking, and cereal grain harvesting. Wallboards, door cases, and mulch have been made from cereal grain straws and sugarcane bagasse; chemical-grade cellulose has been produced from cotton linters, wood, and bast fibers; furfural and brake shoes have been made from bagasse; and various chemicals have been produced from corn cobs. Other examples are limitless, yet this reused cellulose represents only a small fraction of that being dumped, buried, or used as a fuel supplement.

*Mr. Rogers is Senior Research Chemist with SHWRL, NERC-Cincinnati (513/684-4484).

PRODUCTION PROCESSES

Cellulose-to-Protein Pilot Plant

As a result of work done at Louisiana State University (LSU), Callihan and Dunlap (1) designed, constructed, and operated a chemical-microbial pilot plant at Bay St. Louis, Miss., to produce microbial protein from agricultural waste. SHWRL supported this project for 5 years at a cost of approximately $500,000. After construction was completed, the studies were concerned with the technical and economic optimization of the pilot plant (Figure 1).

More basic knowledge of the theory and technique of cellulose fermentation was obtained; means were identified to improve substrate treatment that would enhance fermentation rates, increase cell productivity, and improve cell harvesting. The cellulolytic bacteria used in the study were mixed cultures of *Alcaligenes faecalis* and *Cellulomonas*. Microbial cell concentration of 12 gm per liter and rates of cell synthesis of 1 gm per liter per hr were achieved in batch and, occasionally, in continuous fermentation operations. A 55-percent protein product is produced, and the amino acid profile compares favorably with other protein sources.

In contrast to other on-stream processes for single-cell protein production (such as those developed by British Petroleum in the United Kingdom,

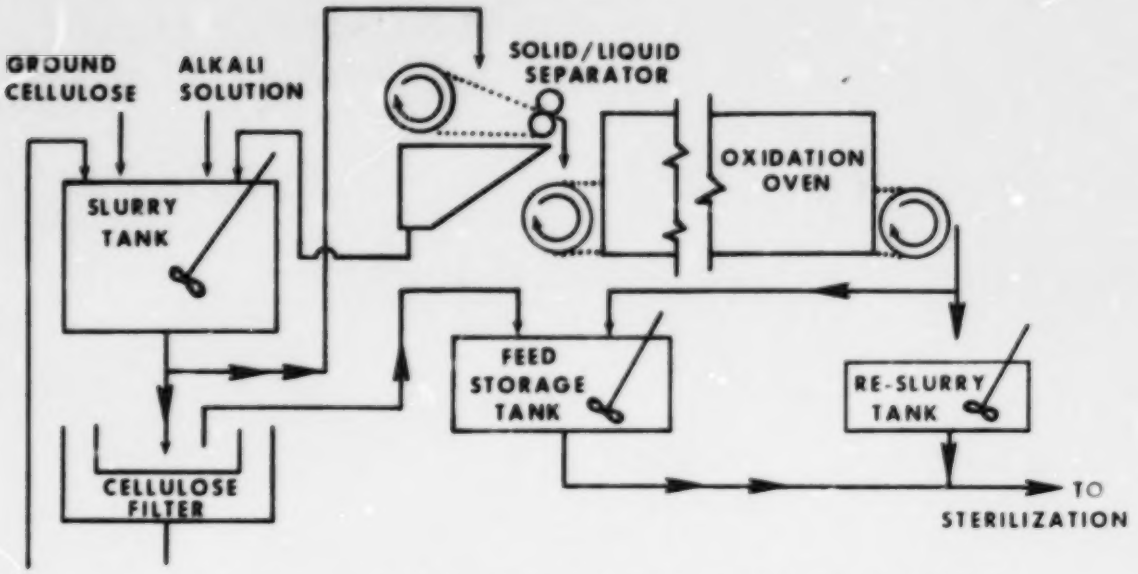

Figure 1. Process flow chart for single cell protein production from cellulosic wastes.

groups in the Soviet Union, and other developers), this LSU process is unique in that it uses cellulose instead of increasingly scarce and expensive hydrocarbons.

This EPA-sponsored research by the LSU group must be considered a highly successful effort, since private capital will provide support leading to a demonstration plant. The LSU group, in conjunction with the Bechtel Corporation, plans construction of a $10 million demonstration plant. Bechtel's reported intention is eventually to build a commercial plant, at a cost of $30 million, that will use waste from a city the size of San Francisco to produce 60,000 tons of protein per year.

Fermentation Technology

Research carried out in laboratories of the SHWRL was directed toward the development of fermentation technology to utilize a variety of cellulosic wastes (2). In contrast to LSU work, fungi rather than bacteria were evaluated as agents to digest cellulose and produce a high-quality protein. Both physical and chemical treatments were evaluated in an attempt to speed up the waste recycling process. Submerged culture techniques were also used to improve the yields of fungal protein. The protein produced ranged from as low as 6.8 to 13.3 percent (protein grains such as corn, wheat, and rye range from 10 to 15 percent). We determined that fungus #6 protein and amino acids (Table 1) are well within the range of cereal grain. Another process for the production of high-quality fungal protein from starch and starchy processing wastes was also developed in the SHWRL. The fungal product resulting from this process is 36 percent protein. A patent application of the process has been filed (3).

Product Testing

A short-term preliminary feed trial with fungal protein and rainbow trout was conducted at Oregon State University Food Science and Technology Laboratory (4). The fungal protein was incorporated at a 25-percent level and fed to young rainbow trout over a period of 2 months. This fungal protein (36 percent) was substituted for fish meal (approximately $400 per ton), and the trout grew as well on this diet as they did on the control feed. The feeding enthusiasm was excellent, and the animals exhibited no signs of toxicity. More extensive fungal protein feeding studies with chicks are on-going at Tennessee State University (5). This study is expected to confirm the nutritional value of fungal protein.

FABRICATION OF MICROBIAL PROTEIN FROM CELLULOSIC WASTE

A research program of fabricating microbial protein at Louisiana State University (6) was concerned with rendering the vast quantities of microbial protein that could be produced from cellulosic

TABLE I. AMINO ACID CONTENT OF SELECTED FUNGI (gram amino acid/100 grams protein)

Amino acid	*A. fumigatus* #3	*A. fumigatus* #6	*Penicillium* sp. #7	*Trichoderma viride* #9	*Chaetomium* sp. #10	*Geotrichium candidum* #11
Alanine	5.90	5.60	5.90	5.10	6.60	6.00
Arginine	3.70	3.80	7.80	4.00	8.20	6.70
Aspartic acid	8.80	8.30	8.90	7.70	10.70	6.40
Cystine, half		0.40				
Glutamic acid	11.00	11.30	13.30	9.90	11.70	11.30
Glycine	5.30	3.80	5.70	5.90	5.80	4.20
Histidine	2.20	1.90	3.30	1.60	4.70	3.20
Isoleucine	7.30	7.20	4.50	4.00	5.60	3.90
Leucine	8.80	10.90	5.70	5.10	6.60	6.70
Lysine	4.40	5.60	5.70	4.40	5.60	5.30
Methionine	7.30	6.50	1.10	2.00		2.70
Phenylalanine	6.10	5.30	4.70	5.50	6.10	7.40
Proline	2.90	3.40	3.60	3.70	2.80	3.20
Serine	5.50	4.10	4.50	2.60	4.20	5.00
Threonine	7.00	4.40	5.60	4.40	4.80	7.40
Tyrosine	3.90	3.00	6.10	3.70	4.20	4.20
Valine	2.60	5.30	6.10	4.80	6.60	12.40

wastes into more generally useful products. The specific aims of the program were to render the fabricated protein more acceptable for food applications and to evaluate the potential of the modified protein as a raw material for fiber blends, biodegradable packaging films, and films for high-strength composites.

At the completion of this grant in February 1974, techniques had been developed to remove nucleic acids and isolates of protein components for potential incorporation into low-protein foodstuffs. Studies to fabricate microbial protein into fibers and films for evaluation in textured foods are now proceeding at the expense of private industry.

ECONOMICALLY FEASIBLE PROCESS MODIFICATIONS

When cellulose modification and protein-producing processes have been fully optimized, further measures may be taken to improve the economic feasibility of producing microbial proteins.

Gray (7) observed that when concentrations of zinc as great as 220 ppm were added to the growth medium, protein synthesis in fungi increased. Similar effects were observed when various concentrations of the herbicide atrazine was evaluated on the following four common fungi cultivated in a liquid medium: trichoderma, fusarium, penicillium, and geotrichum (8). When atrazine at a concentration of 10 ppm is applied, the weight of the mycelium is increased by almost 100 percent.

SHWRL investigated the use of herbicides and zinc as agents to increase the quality and quantity of protein that can be produced from waste. Studies on increasing protein yield with zinc were conducted utilizing the fungus *A. fumigatus*, which is 21 to 22 percent protein and capable of degrading native cellulose. The Kjeldahl nitrogen method and determination of constituent amino acids were the methods used to evaluate the influence of zinc on protein synthesis (9). The Kjeldahl nitrogen increased as parts per million of zinc increased. The importance of an amino acid determination is that it reveals that, although the Kjeldahl nitrogen continued to increase, the nitrogenous products were not amino acids. Therefore, it appears that zinc concentrations up to 60 ppm will stimulate increased protein synthesis and that higher zinc concentrations will cause nonprotein nitrogen compounds to be biosynthesized. SHWRL are theorizing that as zinc approaches toxic levels, the nonprotein nitrogenous compound functions as a protective mechanism. The addition of a predetermined concentration of zinc in fermentation media could play a great role in improving the nutritional value of microbial protein produced from cellulosic wastes and increase the competitiveness of this product with conventional protein sources. Similar findings have also been observed with auxins and herbicides and are the subject of a paper being prepared for publication.

SUGAR FROM CELLULOSE

A proposed technique for waste disposal that would utilize both agricultural and municipal wastes

tear here

as raw material was investigated by Porteous (10). This proposal consisted of hydrolyzing the cellulosic wastes to sugars. The kinetics for hydrolysis of cellulose in paper were experimentally determined over a range of 180 to 240 C, with 0.2 to 1.0 percent acid in a batch reactor (11).

The sugar solution obtained from refuse hydrolysis can be concentrated to 12 percent with the use of a multi-effect evaporator and can be used in commercial fermentation processes. This sugar can be converted by fermentation to ethyl alcohol and could possibly be used as a new source of automotive fuel.

Information from these studies has formed the basis for future investigations supported by contracts and grants on the economic feasibility of producing ethyl alcohol as a fuel in a continuous hydrolysis process. The resulting yeast mass would be used as protein.

CONCLUSIONS

The developments reported here could make a significant impact on meeting the world's protein demand and some impact on the total solid waste disposal problem. The scope of the world's food problem up to the present has been limited mainly to the underdeveloped countries. However, with skyrocketing prices of grain and shortages of fuel and fertilizers, developed nations too may face a staggering food deficit in the near future.

The technology briefly described here may offer a future means to offset the world's protein shortage, since productivity would neither be seasonal nor sensitive to fuel, fertilizers, or other raw materials that are in short supply.

REFERENCES

1. Callihan, C. D., and C. Dunlap. 1968. Construction of continuous chemical-microbial pilot plant to produce edible proteins from cellulosic waste. Contract No. PH-86-68-152. Louisiana State University, Baton Rouge, La. NTIS PB 223-873/AS

2. Rogers, C. J., W. E. Coleman, D. F. Spino, T. C. Purcell, and P. V. Scarpino. 1972. Production of fungal protein from cellulose and waste cellulosics. Environ. Sci. Technol. 6:715-719, Aug.

3. Rogers, C. J., and W. E. Coleman. 1972. Process for the production of high quality fungal protein from starch and starchy processing wastes. Patent application 267,414 filed June 29.

4. Personal Communication. 1973. R. D. Sinnhuber, Professor of Food Science and Technology, Oregon State University, Corvallis, Ore., Aug. 7.

5. Adams, Ozzie. Growth response of chicks fed microbial proteins from organic wastes. On-going EPA Grant R802629-01. Tennessee State University, Nashville, Tenn.

6. Daly, W. H. 1970. Fabrication of single cell protein from cellulosic waste. Grant No. EP-00524, Louisiana State University, Baton Rouge, La.

7. Gray, W. D. 1964. Process for production of fungal protein. U.S. Patent 3,151,036, Sept. 29.

8. Sikka, H. A., R. W. Couch, and A. E. Dows. 1965. Effect of atrazine on the growth and reproduction of soil fungi. Proc. Weed Sci. Soc. 18:116.

9. Coleman, W. E. 1972. Automatic amino acid analysis for determining the amount and quality of protein in fungal protein and in other protein sources. *In* Symposium: Seed Proteins. G. E. Inglett, Ed. Chapter 20:277-283. Avi Publishing Co., Westport, Conn.

10. Porteous, A. 1967. Toward a profitable means of refuse disposal. ASME Publication 67-WA/PTD-2, 17 p.

11. Converse, A. O., H. E. Grethlein, S. Karondikar, and S. Kuhrtz. 1971. A laboratory and economic analysis for acid hydrolysis of cellulose in refuse to sugar and its fermentation to alcohol. Grant No. UI-00597-02. Dartmouth College, Hanover, N.H.

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

ADVANCED WASTE TREATMENT

July 5, 1974

TOXICITY OF WASTEWATER DISINFECTANTS

Robert B. Dean*

Wastewaters are frequently treated with a disinfectant before they are discharged to surface waters to reduce the chance that disease organisms might be transmitted to users of the water. Much has been published in the literature on the efficacy of disinfectants (4) and the design of equipment (5,6,13,14). A reading list is included on page 3 for the benefit of those desiring more information on the technical aspects of disinfection. This newsletter is concerned with the toxic effects that may be produced by disinfectants and with ways to reduce the toxicity.

Disinfectants are substances that are toxic to organisms of health significance at reasonable concentrations. Useful disinfectants for wastewaters either decompose rapidly or they are nontoxic to humans at concentrations that will still kill bacteria. Many wastewaters are routinely chlorinated before discharge in order to destroy indicator bacteria and meet public health standards. Chlorine is usually applied to wastewater in quantities sufficient to reduce the count of intestinal bacteria to acceptable levels. Only one out of a hundred thousand or so of the bacteria found in wastewater is actually capable of causing disease in man. The vast majority are common intestinal bacteria that serve a useful function in the body. It can be assumed that if the intestinal indicator bacteria have been killed by a disinfectant, then pathogenic bacteria, which are less resistant, will also be reduced to acceptable levels (4). Chlorination can produce substances toxic to fish and other aquatic organisms (16-29). Public health aspects, however, have taken precedence over other ecological effects and disinfection of wastewaters is required whenever discharge without disinfection will cause a health problem. The EPA standard for secondary discharges has recently been established at 200 fecal coliform per 100 ml (42).

*Dr. Dean is Acting Science Adviser, AWTRL, NERC-Cincinnati (513/684-8231).

Chlorine is the least expensive disinfectant that can be used to meet current standards (43). Approximately 200,000 tons of chlorine are used annually in wastewater treatment (11). Three well-known alternatives to chlorination are: chlorine dioxide (41), ozone (30-35), and ultraviolet (UV) (39,40). There are no recorded observations of toxic byproducts produced when water is disinfected by any of these three. Ozone itself is toxic, but it decays with a half life of 20 minutes in pure water and more rapidly in contaminated waters. Chlorine dioxide (ClO_2) also decays fairly rapidly, but since chlorine dioxide is made on site from chlorine (Cl_2) and sodium chlorite , some free chlorine will also be present. UV leaves no byproduct, but it is not effective in turbid waters because the light cannot penetrate solid particles and will not kill the bacteria inside the particles. All three alternatives for disinfection are more expensive than chlorine (43) and all three are difficult to monitor to ensure adequate disinfection. For special purposes, any one of the three may be used but chlorine probably will remain the dominant disinfectant for wastewaters including industrial and cooling water discharges.

When chlorine is dissolved in water, it may exist in several different forms depending on the pH and other substances present. Free chlorine exists predominantly as a mixture of hypochlorous acid and hypochlorite ions (Figure 1) (9,13). Free chlorine decomposes eventually to chlorides unless it is converted to less active substances. In wastewaters, chlorine reacts very rapidly with ammonia (NH_3) to produce chloramines such as monochloramine (NH_2Cl). Chloramines are bactericidal though to a lesser degree than free chlorine (4). The sum of free chlorine and chloramines is referred to as available chlorine.

Monochloramine is often used to provide limited protection against reinfection in water supply lines

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$
hypochlorous acid

$$HOCl \rightarrow H^+ + OCl^-$$
pK = 7.5 hypochlorite ion

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$
monochloramine

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$
dichloramine

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$
nitrogen trichloride

$$NH_2Cl + NHCl_2 \rightarrow N_2 + 3H^+ + 3Cl^-$$

$$2NH_3 + 3Cl_2 \rightarrow N_2 + 6H^+ + 6Cl^-$$

Figure 1. Reactions of chlorine with water and ammonia.

since it decomposes much more slowly than free chlorine (3). Residual available chlorine in wastewaters ranges from 1 to 10 mg/l (parts per million) in waters that have been adequately disinfected. Residual chloramines are essentially useless against other bacteria after the wastes have been diluted in surface waters. If large quantities of chlorine are added to water, all of the ammonia can be oxidized (8,12). From 8 to 10 parts of chlorine per part of ammonia nitrogen are required to remove all of the ammonia at what is called the breakpoint. Any chlorine added in excess of the breakpoint will remain as free chlorine. Both free chlorine and chlorine available in chloramines are toxic to fish and other aquatic organisms at concentrations down to 0.002 mg/l (2 parts per billion) corresponding to dilutions of chlorinated wastes of up to one-thousand fold (18,29). Fish kills have been caused by chlorine in condenser water discharged by power plants in Michigan (25) and in dechlorinated power plant discharges (19). Toxic effects of sewage discharged to salt water have also been related to the chlorine content (26). Although fish are repelled by low levels of chlorine in water and frequently can escape in time, other aquatic organisms in the food chain may be killed by chlorine discharges.

Available chlorine residuals can be reduced essentially to zero by sulfur dioxide (SO_2) or sulfites and, thus, can greatly reduce the acute toxicity of the disinfected wastewater (1,12). The technology of dechlorination with sulfur dioxide is old (7) and straightforward (Figure 2) (12,13). There are no toxic effects from slight excesses of sulfur dioxide. A 70-mgd plant for dechlorinating effluents discharged to San Francisco Bay has been designed to meet California state standards (15). There are problems with maintaining chlorine detector electrodes at zero-free chlorine but they can be solved. Chlorine can also be removed on activated carbon (2). Dechlorination by carbon columns is being studied in the Physical-Chemical Section, Advanced Waste Treatment Research Laboratory of the National Environmental Research Center in Cincinnati, Ohio.

$$2NH_3 + 3Cl_2 \rightarrow N_2 + 6H^+ + 6Cl^-$$

$$SO_2 + HOCl + H_2O \rightarrow SO_4^= + Cl^- + 3H^+$$

$$SO_2 + NH_2Cl + 2H_2O \rightarrow SO_4^= + Cl^- + 2H^+ + NH_4^+$$

$$C^* + 2HOCl \rightarrow CO_2 + 2H^+ + 2Cl^-$$

$$C^* + 2NH_2Cl + 2H_2O \rightarrow CO_2 + 2NH_4^+ + 2Cl^-$$

$$C^* + 4NHCl_2 + 2H_2O \rightarrow$$
$$CO_2 + 2N_2 + OH^+ + 8H^+ + 8Cl^-$$

Figure 2. Dechlorination reactions.

The cost of dechlorination by sulfur dioxide will not exceed the chemical costs of chlorination because the two chemicals have the same cost per chemical equivalent and have similar physical properties. According to G. C. White (12), no additional sensors are needed to control the sulfur dioxide feed and no contact chamber is needed. For all practical purposes, the dechlorination reaction is instantaneous in the pH range of 7 to 8. In ordinary disinfection, less than half of the chlorine remains as chlorine residual so the sulfur dioxide costs should not exceed 60 percent of the chlorine chemical costs (10). When chlorine is used for breakpoint removal of ammonia, the additional chemical cost of dechlorination will be trivial. Less than half the cost of chlorination lies in the chemical itself according to work done for the EPA by Black and Veatch (36). Therefore, disinfection followed by dechlorination should cost not more than 1.3 times the cost of disinfection and may be as low as 1.2 times that cost. Since sulfur dioxide also removes some of the dissolved oxygen, it may be necessary to reaerate waters that have been dechlorinated.

Organic substances in wastewaters will react with chlorine to produce toxic residues that cannot be detoxified by sulfur dioxide (16). Phenol, for example, and forms mono-, di-, and tri-chlorophenols all are toxic to aquatic organisms (Figure 3) (22). Many other chlorinated compounds have been identified in chlorinated wastes (23). About 1 percent of the chlorine ends up in stable organic compounds when municipal wastes are chlorinated. This corresponds to an annual discharge of about 2,000 tons per year of potentially toxic, environmentally persistent substances. Chlorination of industrial wastes from coke ovens and wood treatment plants and chlorination of domestic wastes from areas that use

cresol as a household disinfectant could produce significant toxic discharges. Chlorination of sludge probably produces persistent chlorinated compounds. Heavily chlorinated sludge is resistant to putrefaction for long periods, which may indicate the presence of biocidal substances (37,38). If the supernatant from chlorinated sludge is returned to the treatment plant for biological treatment, it may be detoxified. Better data are needed, however, before it will be possible to recommend for or against sludge chlorination. Further evidence that bacterial activity is reduced in chlorinated effluents after dechlorination may be inferred from data presented in references 24 and 27.

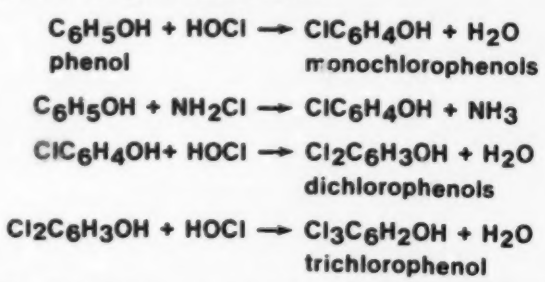
$C_6H_5OH + HOCl \rightarrow ClC_6H_4OH + H_2O$
phenol
monochlorophenols
$C_6H_5OH + NH_2Cl \rightarrow ClC_6H_4OH + NH_3$
$ClC_6H_4OH + HOCl \rightarrow Cl_2C_6H_3OH + H_2O$
dichlorophenols
$Cl_2C_6H_3OH + HOCl \rightarrow Cl_3C_6H_2OH + H_2O$
trichlorophenol

Figure 3. Reactions of available chlorine with phenols.

It should be emphasized that by far the greatest part of the toxicity produced by chlorine disinfection is removed by dechlorination. In one study by the University of California at Berkeley, no residual toxicity was detected after dechlorination (20). Nevertheless, the production of persistent toxic compounds is possible and in some situations may have an environmental impact (21).

Experimental work on the toxicity of residuals from various disinfection processes in fresh water systems is coordinated through the National Water Quality Laboratory, 6201 Congdon Boulevard, Duluth, Minnesota 55804. Dr. William Brungs is the responsible scientist, telephone (218) 727-6547. Work on salt water systems is carried out at the Gulf Breeze Environmental Research Laboratory, Sabine Island, Gulf Breeze, Florida 32561. Mr. Gary Cooke is the responsible scientist, telephone (904) 932-5326. A pilot study of disinfection with chlorine, ozone, and bromine chloride and dechlorination with sulfur dioxide is being carried out at Wyoming, Michigan. Mr. Cecil Chambers, Advanced Waste Treatment Research Laboratory (AWTRL), NERC–Cincinnati, is the project officer, telephone (513) 684-8328. Breakpoint chlorination and dechlorination is coordinated through the Municipal Waste Treatment and Reuse Section, AWTRL. Mr. Francis L. Evans III is the responsible scientist, telephone (513) 684-8236. Work on the identification of chlorinated organic compounds produced by disinfection is being coordinated by Dr. Wayne Garrison at the Southeast Environmental Research Laboratory, College Station Road, Athens, Georgia 30601, telephone (404) 546-3187. There are several contracts and university grants funded by the EPA to study the production and behavior of chlorinated byproducts from disinfection.

REFERENCES

Chlorine Technology

1. Baker, R. A. 1964. Dechlorination and Sensory Control. JAWWA,* 56(12):1578-1592.
2. Bauer, R. C., and V. L. Snoeyink. 1973. Reactions of Chloramines with Active Carbon. JWPCF,† 45(11):2290-2301.
3. Buelow, R. W., and G. Walton. 1971. Bacteriological Quality vs. Residual Chlorine. JAWWA, 63(1):28-35.
4. Chambers, C. W. 1971. Chlorination for Control of Bacteria and Viruses in Treatment Plant Effluents. JWPCF, 43:228-241.
5. Kokoropoulos, P. 1973. Designing Post-Chlorination by Chemical Reactor Approach. JWPCF, 45:2155-2165.
6. Kothandaraman, V., H. L. Southerland, and R. L. Evans. 1973. Performance Characteristics of Chlorine Contact Tanks. JWPCF, 45:611-619.
7. Menzies, S. H. 1917. Treatment of Water, Sewage, and the Like. U.S. Patent 1,229,305, June 12.
8. Pressley, T. A., and D. F. Bishop, Jr. 1973. Nitrogen Removal from Waste Water by Breakpoint Chlorination. U.S. Patent 3,732,164, May 8.
9. Sconce, J. S. 1962. Chlorine, Its Manufacture, Properties and Uses. American Chemical Society Monograph No. 154. Reinhold Publishing Co., New York.
10. Snoeyink, V. L., and F. I. Markus. 1974. Chlorine Residuals in Treated Effluents. Water & Sewage Works, 121(4):35-38.
11. Ward, P. S. 1974. Chlorine for Effluents in Short Supply. JWPCF, 46(1):2-4.
12. White, G. C. 1968. Chlorination and Dechlorination: A Scientific and Practical Approach. JAWWA, 60:540-561.
13. White, G. C. 1972. Handbook of Chlorination. Van Nostrand, Reinhold Co., New York.
14. White, G. C. 1974a. Disinfection Practices in the San Francisco Bay Area. JWPCF, 46:89-101.
15. White, G. C. 1974b. Personal communication.

Toxic Substances Produced by Chlorination

16. Barnhart, E. L., and G. R. Campbell. 1972. Effect of Chlorination on Selected Organic Chemicals. NTIS‡ PB 211 160. 105 pp.
17. Basch, R. E. 1971. In Situ Investigations of the Toxicity of Chlorinated Municipal Wastewater Treatment Plant Effluent to Rainbow Trout. Am. Chem. Soc. Div. Water, Air and Waste Chem. Abstracts, September Meeting. p. 92-94. (NTIS PB 209 890).

*Journal American Water Works Association
†Journal Water Pollution Control Federation
‡National Technical Information Service, Springfield, Va. 22151.

18. Brungs, W. A. 1973. Effects of Residual Chlorine on Aquatic Life. JWPCF, 45:2180-2193.
19. Brungs, W. A. 1974. Chlorinated Organics Toxic in Condenser Water Discharge. Personal communication.
20. Esvelt, L. A., W. J. Kaufman, and R. F. Selleck. 1973. Toxicity Assessment of Treated Municipal Wastewater. JWPCF, 45(7):1558-1572.
21. Ingols, R. S. 1973. The Role of Disinfection in the Optimum Environment. Water Treatment and Examination, 22(3):147-152.
22. Ingols, R. S., P. E. Gaffney, and P. C. Stevenson. 1966. Biological Activity of Halophenols. JWPCF, 38(4):629.
23. Jolley, R. L. 1973. Chlorination Effects on Organic Constituents in Effluents from Domestic Sanitary Sewage Treatment Plants. Water Pollution Control Federation Meeting, Cleveland, Ohio, September.
24. Lin, S. 1973. Evaluation of Coliform Tests for Chlorinated Secondary Effluents. JWPCF, 45:498-505.
25. McLean, R. I. 1973. Chlorine and Temperature Stress on Estuarine Invertebrates. JWPCF, 45:837.
26. Muchmore, D., and D. Epel. 1973. Effects of Chlorination of Waste Water on Fertilization in Some Marine Invertebrates. Chemical Abstracts, 79:34798n.
27. Susag, R. H. 1968. BOD Reduction by Chlorination. JWPCF, 40(11):R434-R444.
28. Taras, M. J. 1953. Effect of Free Residual Chlorination on Nitrogen Compounds in Water. JAWWA, 45:47-61.
29. Zillich, J. A. 1972. Toxicity of Combined Chlorine Residuals to Freshwater Fish. JWPCF, 44:212-220.

Ozone

30. Evans, F. L., III. 1972. Ozone in Water and Wastewater Treatment. Scientific Publications, Inc., Ann Arbor, Michigan.
31. Majumdar, S. B., W. H. Ceckler, and O. J. Sproul. 1973. Inactivation of Poliovirus in Water by Ozonation. JWPCF, 45:2433.
32. Nebel, C., R. D. Gottschling, R. L. Hutchison, et al. 1973. Ozone Disinfection of Industrial-Municipal Secondary Effluents. JWPCF, 45:2493-2507.
33. Rosen, H. M. 1973. Use of Ozone and Oxygen in Advanced Wastewater Treatment, JWPCF, 45(12): 2521-2536.
34. Sliter, T. S. 1974. Ozone: An Alternative to Chlorine. JWPCF, 46(1):4-6.
35. Wynn, C. S., B. S. Kirk, and R. McNabley. 1973. Pilot Plant for Tertiary Treatment of Waste Water with Ozone. AIChE Symp. Ser. 69(129):42-60.

Miscellaneous

36. Black and Veatch Engineers. 1971. Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities. EPA Water Pollution Control Research Series 17090 DAN 09/71, September (NTIS PB 211 132).
37. Goldberg, A. S. 1971. Method for Disposing of Sludge from Sewage and Industrial Wastes. U.S. Patent 3,561,598, February 9; See also JWPCF, 43(9):1912-1920.
38. Greich, E. R., and J. W. Hood. 1967. Purification of Putrescible Unstable Wastes. U.S. Patent 3,300,402, January 24.
39. Huff, C. B., H. F. Smith, W. D. Boring, and N. A. Clarke. 1965. Ultraviolet Disinfection. Public Health Reports, 80(8):695-705.
40. Jepson, J. D. 1973. Disinfection of Water Supplies by Ultra-Violet Radiation. Water Treatment and Examination, 22(3):175-193.
41. Malpas, J. F. 1973. Disinfection of Water Using Chlorine Dioxide. Water Treatment and Examination, 22(3):209-221.
42. U.S. Environmental Protection Agency. 1973. Water Programs. Secondary Treatment Information. Federal Register, 38(159II):22298, Aug. 17.
43. Yao, K. M. 1972. Is Chlorine the Only Answer? Water and Wastes Engineering, 9(1):30-31.

☆ U.S. GOVERNMENT PRINTING OFFICE 1974— 758-496/1251

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

METHODS DEVELOPMENT AND QUALITY ASSURANCE RESEARCH

September 27, 1974

BGM: A NEW CELL LINE FOR RECOVERING VIRUSES FROM WATER

Daniel R. Dahling, Gerald Berg, Donald Berman, Robert S. Safferman*

INTRODUCTION

Primary and continuous cells constitute the two basic types of cell culture systems used in viral research.

Primary cell cultures are derived directly from living tissue which is minced and chemically treated, usually with an enzyme such as trypsin, to liberate individual cells and clumps of cells from the tissue. These cells are washed, suspended in a medium that will support their growth, and placed in test tubes or bottles. The cells attach themselves to the glass and within a week grow into a confluent sheet. Cell cultures in this condition, with fresh medium added as required, may be used for growing viruses (Figure 1). Fresh primary cell cultures must be prepared frequently because they survive for only a few weeks.

Continuous cell lines are derived from primary cells and are developed by successive, periodic reculturing of these cells. Continuous lines are difficult to establish, but once developed, they may often be propagated indefinitely. Many such cell lines existing today originated a decade or more ago.

Both cell culture systems have advantages and disadvantages. The one used depends on many factors, the most important being susceptibility of the cell system to the viruses studied.

Primary kidney cell cultures from African green and rhesus monkeys served as the major laboratory systems for recovering enteroviruses and reoviruses. Charged with improving existing virus methodology, we sought to establish a continuous cell line that would be at least as sensitive as these primary cells to enteroviruses and reoviruses.

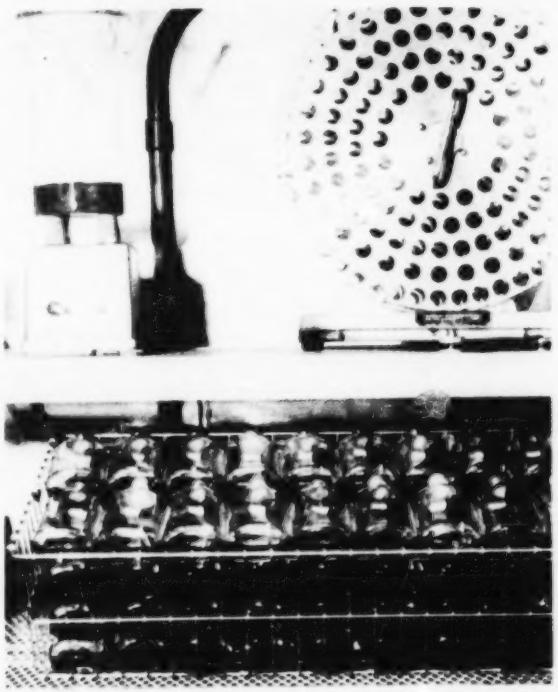

Figure 1. Tissue Culture Methods for Quantitation of Viruses. (Note Roller Drum Apparatus Used in the Application of the Most Probable Number Method for Estimating Concentrations of Viruses by the Test Tube Tissue Culture Technique.)

Far exceeding our expectations was the BGM cell line established from primary African green monkey (*Cercopithecus aethiops*) kidney cells by Dr. Almen Barron of the University of Buffalo.[1] This continuous cell line proved more sensitive to many enteroviruses and one reovirus than primary kidney cells of rhesus or

*The authors are with the Biological Methods Branch of the Methods Development and Quality Assurance Research Laboratory, NERC-Cincinnati (513-684-8262). Mr. Dahling and Mr. Berman are microbiologists in the Virology Section, Dr. Safferman is Chief of the Section, and Dr. Berg is Chief of the Branch.

African green monkeys. It was also shown to be capable of recovering more viruses from sewage and natural waters than the primary lines.

TEST SYSTEM

To determine the relative viral sensitivities of BGM and primary kidney cells of rhesus and African green monkeys, comparative studies were undertaken with viruses of human source that occur in sewage, primary and secondary sewage effluents, and surface waters from various parts of the country. Samples were taken from nine cities along the Missouri River, four cities on the New Jersey coast, two cities in southern Ohio, one city in southern Indiana, and two cities in southern Florida. Ocean water from New Jersey and river water from Indiana were also examined for viruses. Sampling spanned the period from December 1971 to May 1973 and encompassed all four seasons of the year.

Viruses were recovered from sewage and effluents by a low pH membrane filter technique. $MgCl_2$ was added to sewage and sewage effluents to increase virus adsorption to the filter. The pH was lowered to 3 with 1 N HCl and the samples were filtered through 0.45 μm Millipore membranes. Viruses were recovered from river or ocean water samples by a similar method, or by adsorption of the viruses at pH 5 or 6 to polyelectrolyte PE-60[2] layered in a filtration device.

Viruses were eluted from membranes with 3% beef extract at pH 8,[3] and from PE-60 with borate buffer containing 10% fetal calf serum at pH 9. The eluates were divided and inoculated into BGM, rhesus monkey kidney, or African green monkey kidney cultures.

Virus enumeration was carried out by the plaque assay technique which is a direct count method that is similar to the plate culture method for bacterial counting. With this technique, prepared test samples are placed in contact with confluent cell sheets attached to glass in ordinary prescription bottles and viruses are allowed to adsorb to the cells. Two hours are required for maximum virus adsorption.

An agar medium containing neutral red in nutritive material for the cells is then added. As degeneration of virus-infected cells progresses, the pink color imparted to them by the neutral red stain disappears, leaving clear circular areas or plaques (Figure 2). Although each plaque may contain millions of viral particles by the time it is visible, it represents an initial infection by either one viral particle or a clump of viral particles, designated the plaque-forming unit (PFU).

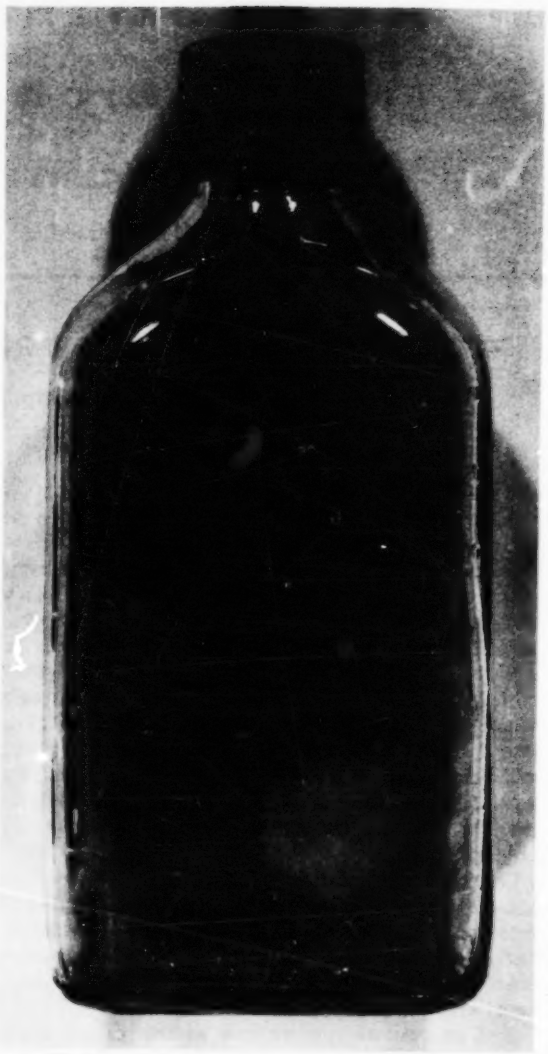

Figure 2. Viral Plaque Formation on BGM Continuous Cell Line.

RELATIVE RECOVERIES OF VIRUSES

Sewage and Effluents

Greater recoveries of viruses were obtained in BGM cells than in primary rhesus cells from 46 of 47 samples of sewage and effluents tested. Usually BGM cultures yielded at least two to three times as many (and sometimes 20 times as many) viruses as rhesus cultures yielded (Table 1).

Because earlier experiences showed that primary kidney cells from African green monkey were more sensitive to many enteroviruses than those from rhesus monkey, the relative effectiveness of BGM and both types of primary monkey cells were compared for recovering viruses from sewage and sewage effluents. The results showed that, although primary kidney cells from African green monkey yielded more viruses than those from rhesus monkey, the former never approached BGM cells in sensitivity (Table 2).

TABLE 1. COMPARATIVE RECOVERIES OF VIRUSES FROM TREATED AND UNTREATED WASTE WATERS IN BGM AND PRIMARY RHESUS MONKEY KIDNEY CELLS

Wastewater sample	PFU recovered/2-liter volume	
	BGM	Primary Rhesus Kidney
Raw sewage	93	35
	22	20
	81	40
	1285	73
	396	26
Primary	412	117
	12	11
	67	42
	41	2
	370	101
	63	20
Chlorinated primary	660	279
	101	0
	185	4
	1082	41
	730	28
Primary solids	151	62
	19	12
	101	67
Chlorinated primary solids	50	25
	12	17
	6	1
Secondary	110	100
	9	2
	212	57

TABLE 2. COMPARATIVE RECOVERIES OF VIRUSES FROM SEWAGE AND TREATED EFFLUENTS IN BGM AND PRIMARY KIDNEY CELLS FROM AFRICAN GREEN AND RHESUS MONKEYS

Wastewater sample	PFU recovered/2-liter volume		
	BGM	Primary African green kidney	Primary rhesus kidney
Raw sewage	173	78	48
	129	52	42
	10	2	4
	91	19	9
Primary	29	5	4
Chlorinated primary	255	47	19
Secondary	18	4	1

Natural Waters

Comparative studies in natural waters yielded recovery results similar to those obtained with sewage and effluents (Table 3). As many or more viruses were detected in BGM cultures as in primary rhesus monkey cell cultures. The greater sensitivity of BGM cells was evident from studies of ocean water, river water, and solids from these waters.

VIRAL SENSITIVITY OF BGM

BGM cells were at least as sensitive and usually more sensitive than rhesus monkey kidney cells to polioviruses 1-3, echoviruses 3, 6, 7, 9, 11, and 27, coxsackieviruses B1-B3, and reovirus 1 that had been grown either in primary cells of rhesus or African green monkeys or in Vero cells. Only echovirus 12 may have done somewhat better in primary rhesus monkey cells, and only coxsackievirus A9 unquestionably found a more sensitive host in the primary cells.

TABLE 3. COMPARATIVE RECOVERIES OF VIRUSES FROM RIVER AND OCEAN WATERS IN BGM AND PRIMARY RHESUS MONKEY KIDNEY CELLS

Sample	PFU recovered/500-liter volume	
	BGM	Primary rhesus kidney
Ocean water	4	1
	3	0
Ocean water solids	3	0
River water	18	0
River water solids	3	0
	3	3
	50	5
Storm sewer at river	2703	32
Storm sewer solids	1280	45

CONCLUSION

The BGM continuous cell line showed superior viral sensitivity and was far superior to commonly used primary monkey kidney cell cultures in securing effective viral recovery in sewage, sewage effluents, and natural waters. The discovery of this practical application of BGM exemplifies the importance of basic research in bringing about innovations in monitoring technology and enforcement activities.

REFERENCES

1. Barron, A. L., C. Olshevsky, and M. M. Cohen. 1970. Characteristics of the BGM line of cells from African green monkey kidney. Archiv fur die gesamte Virusforschung 32:389-392.

2. Wallis, C., J. L. Melnick, and J. E. Fields. 1970. Detection of viruses in large volumes of natural waters by concentration on insoluble polyelectrolytes. Water Res. 4:787-796.

3. Rao, C. V., U. Chandorkar, N. U. Rao, P. Kumaran, and S. B. Lakhe. 1972. A simple method for concentrating and detecting viruses in wastewater. Water Res. 6:1565-1576.

We thank you for responding to our circulation inquiry and hope that you'll find topics of interest in upcoming issues of our newsletter. Future subjects will include:

Coal Refuse Disposal in the Eastern United States

A Copper-Cadmium Column for Manually Determining Nitrate

Granular Media Filtration of Secondary Effluent

The NERC-Cincinnati Electron Microscope Facility

Poliovirus and Bacterial Indicators of Fecal Pollution in Landfill Leachates

Radiorespirometry: A Technique for Rapid Toxicological Screening of Environmental Pollutants

Recreational Water Quality Criteria

Striving for Zero Discharge of Industrial Wastes

A Swirl Device for Regulating and Concentrating Combined Sewer Overflows

☆ U.S. GOVERNMENT PRINTING OFFICE 1974 — 657-050/1052

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

ENVIRONMENTAL TOXICOLOGY RESEARCH

October 11, 1974

RADIORESPIROMETRY: RAPID TOXICOLOGICAL SCREENING OF ENVIRONMENTAL POLLUTANTS

S. D. Lee, R. M. Danner, L. McMillan, W. Moore, Jr., and J. F. Stara*

BACKGROUND

An important function of the U.S. Environmental Protection Agency is to compile criteria documents and to propose environmental standards for various pollutants to prevent further deterioration of our environment and to improve the environmental quality for the present and future generations of this country.

The importance of the criteria document is well recognized; but it can only be as sound and complete as the available scientific information based on health-effects research. Without a doubt, the experimental results from human health-effects research would be the most desirable type of information upon which to base the standards; but humans cannot be used as experimental subjects in studies of effects of the majority of pollutants or toxicants. We must therefore rely on information obtained from investigations with experimental animals and other biological systems.

Scientists in this area have the responsibility of providing accurate scientific data based on experiments employing, among others, "practical and relevant" concentrations of pollutants. Extrapolation of data from short-term studies that employed high concentrations of pollutants may not be applicable, even though this approach is often used.

Many investigators have reported on the biological effects of various pollutants; but there is still a paucity of information concerning the effects of pollutants on biochemical interactions, especially at low, relevant concentrations of pollutants using in vivo systems in nonterminal experiments.

In addition, the ability to conduct repetitive testing on the same animal is desirable, with the advantage of using the same animal as its own control. This technique allows the study of cumulative effects of pollutants as well as the investigation of the processes of recovery from certain effects. In general, in vivo experimental data carry much more weight in terms of their usefulness for establishing or modifying standards.

Our primary objective has been to develop new techniques or to apply existing methods that are capable of detecting early biochemical lesions, before the appearance of overt toxic symptoms, resulting from low concentrations of environmental pollutants. For this puspose, we have employed a technique called "radiorespirometry."[1-15] This technique is used to measure expired $^{14}CO_2$ in a biological system metabolizing ^{14}C-labeled compounds. Information obtained by the continuous measurement of rate and magnitude of $^{14}CO_2$ from specifically labeled substrates has contributed significantly towards understanding the degree of participation of various pathways of glucose metabolism and many other metabolic processes. In addition, CO_2 excretion responds rapidly to changes in the metabolic alterations of the body – the only carbon excretion product to do so. Breath excretion of ^{14}C following administration of a labeled organic compound can, therefore, be used in intact animals to study the metabolism of specific compounds and of a particular labeled carbon atom in the compound. Furthermore, if the respiratory pattern of a given labeled compound has been established in an animal system, a variation in this pattern can indicate a change of the physiological or biochemical state of the animal.

MATERIALS AND METHODS

The animal exposure system and associated instrumentation are depicted in Figure 1. The labeled compound

*The authors are with the Environmental Toxicology Research Laboratory at the National Environmental Research Center in Cincinnati. Dr. Lee (513-684-7414) is Chief of the Biochemistry Section; Mr. Danner is a chemist and Mr. McMillan is a biologist in that Section; Dr. Moore is Chief of the Experimental Toxicology Branch; and Dr. Stara is Director of the Laboratory.

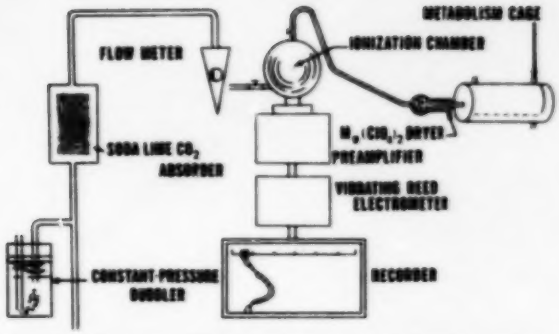

Figure 1. Apparatus Used to Measure and Record Expired $C^{14}O_2$ Activity.

was administered intravenously through the tail vein of the rat, who was then placed immediately in the glass metabolism cage (approx. 1500-ml volume) for the continuous measurement of ^{14}C in expired air throughout the 4-hr experimental period. Filtered air (250 ml per min) was passed through the metabolism cage to sweep out respired CO_2 containing ^{14}C. This air was then drawn through the 500-ml-volume spherical ionization chamber for quantitation of radioactivity. The measurement of electric current from the ionization chamber was accomplished by the use of a vibrating reed electrometer. The potential was then amplified and recorded as a deflection in amperes or volts on a strip chart recorder for immediate observation. Simultaneously, all the information was punched on a paper tape for data reduction on a computer. Our system allows us to run four animals concurrently, usually two controls and two exposed.[2]

We have used this method for examining gaseous pollutants by inhalation and food chain pollutants by ingestion. With this method, the experimental animals do not have to be anesthesized; they are rather free to move about under "normal" conditions while they are being tested.

RESULTS AND DISCUSSION

Effect of SO_2 Exposure

The effect of SO_2 exposure on $^{14}CO_2$ output following U-^{14}C-glucose administration was studied in terms of the cumulative percent of carbon-14 expiration of the injected dose. The results from experiments using different concentrations of SO_2 are summarized in Table 1. "Zero percent" alteration was assigned to the observed values in control animals for purposes of comparison. When the SO_2 concentrations were higher than 27.7 ppm, there was a decrease in $^{14}CO_2$ output; below this concentration, an increase of $^{14}CO_2$ output was observed in the expired air. This "crossover" pattern of response to SO_2 dose is interesting; the results may have a possible relationship to the alterations in respiratory functions observed by Amdur et al.[16] and by this

TABLE 1. EFFECT OF SO_2 EXPOSURE CONCENTRATIONS ON CUMULATIVE ^{14}C OUTPUT FOLLOWING RADIOLABELED-GLUCOSE INJECTION

Group	SO_2 concentration (ppm)	Alteration of ^{14}C output (%)
Control	–	0*
1	200.0	-19.4
2	150.0	-14.6
3	107.0	- 8.5
4	45.0	- 6.09
5	27.7	- 3.73
6	15.0	+ 8.99
7	13.0	+ 0.98
8	12.5	+ 7.17
9	3.7	+ 6.11

*Zero percent alteration was assigned to the control experiments for purposes of comparison.

laboratory as well.[17] Both research groups independently showed increased tidal volumes accompanied by decreased respiration rates with high concentrations of SO_2 (above 25 ppm), and decreased tidal volumes along with increased respiration rates with lower SO_2 concentrations (below 10 ppm). Thus far, we are unable to offer a reasonable explanation for the crossover phenomenon.[17]

A representative experiment in which ^{14}C-palmitate was used as the substrate is shown in Figure 2. In a 4-hr experimental period, the control group excreted 49

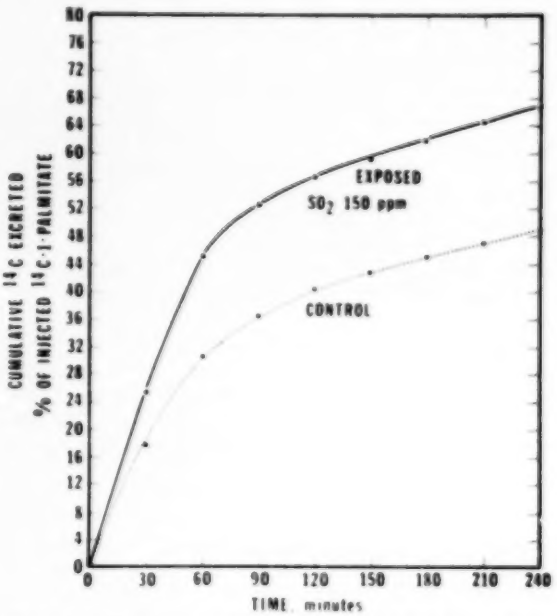

Figure 2. Effect of SO_2 Exposure on Cumulative Excretion of ^{14}C Following Injection of ^{14}C-1-Palmitate.

percent of injected ^{14}C as compared with 66 percent in the animals exposed to 150 ppm of SO_2, resulting in a net increase of 33 percent. This is a reverse phenomenon from that observed in the study where glucose was used as the substrate.

Table 2 shows a summary of the effect of five different concentrations of SO_2 exposures on cumulative ^{14}C output following radiolabeled-palmitate injection. An increase in ^{14}C excretion was observed for all five concentrations used; with SO_2 concentrations of 24 and 15 ppm, a decreasing trend was noted. Additional studies utilizing lower concentrations of SO_2 should offer further clarification of these observations. Furthermore, the use of glucose labeled at different positions with ^{14}C should provide an insight into the mechanism of observed metabolic alteration.

TABLE 2. EFFECT OF SO_2 EXPOSURE CONCENTRATIONS ON CUMULATIVE ^{14}C OUTPUT FOLLOWING RADIOLABELED-PALMITATE INJECTION

Group	SO_2 concentration (ppm)	Alteration of ^{14}C output (%)
Control		0*
1	150	+29.35
2	100	+37.94
3	50	+35.94
4	25	+24.13
5	15	+15.33

*Zero percent alteration was assigned to the control experiments for purposes of comparison.

Results obtained thus far from experiments using both ^{14}C-labeled glucose and palmitate indicate an effect similar to the "Pasteur effect," which refers to an inhibition of glycolysis and which in turn causes an increased activity of lipid metabolism.[18]

Effects of Methylmercury Chloride

Intragastric administration of methylmercury chloride 24 hr before testing suppressed $^{14}CO_2$ output following intravenous injection of 1-^{14}C-glucose. Following the initial treatment with 0.05 mg and 0.10 mg per kg body weight, decreases of 6.6 and 12.1 percent in respired $^{14}CO_2$ were observed, respectively (Table 3). When the same treatment was repeated for each group of animals, metabolic suppression of 17.9 percent for the 0.05-mg group and 30.8 percent for the 0.10-mg group was observed. The yardstick for comparison is cumulative percent $^{14}CO_2$ output in the first 4-hr period.

Caution must be used in interpreting these data. The changes reported here may or may not be detrimental to the animals. Our data at this time merely indicate an alteration from the normal pattern of glucose catabolism, and it is not clear whether there is some kind of adaptive mechanism at work or if the alteration is truly a manifestation of toxic effect.

TABLE 3. EFFECT OF REPEATED DOSES OF METHYLMERCURY CHLORIDE ON CUMULATIVE $^{14}CO_2$ OUTPUT AFTER C-1-GLUCOSE INJECTION

Experimental group	% Alteration for first dose	% Alteration for second dose
Control	0	0
0.05 mg/kg B.W.	- 6.6	-17.9
0.10 mg/kg B.W.	-12.1	-30.8

However, the significance of our data is that a biochemical change was detectable at low concentrations of 0.05 and 0.1 mg per kg levels, in vivo, and this calls for attention to an area of research that has been neglected or avoided by many. Furthermore, the toxicity of methylmercury appears to be influenced by other factors, such as the presence of selenium. Ganther et al.[19] demonstrated with quails that 20 ppm methylmercury in diets containing 17 percent (by weight) tuna was less toxic than the same concentration of methylmercury in corn soya diet. These investigators also showed, with rats, that selenium content in the diet comparable to that contained in the tuna decreased methylmercury toxicity. Tuna meat contains a relatively high concentration of selenium. Selenium in tuna is not a hazard in itself, and it may lessen the danger of mercury poisoning in man following ingestion of mercury-contaminated tuna. The evidence to indicate that different effects are manifested when mercurials are given in rather pure form versus in combination with certain compounds is very important and should be taken into consideration for the criteria documents or standards, since no one eats methylmercury chloride (CH_3HgCl) or any other chemical in its pure form.

Miller et al.[20] have shown histopathological lesions at all levels in the cerebral cortex of dogs after mercury was administered at the rate of 3 mg per kg body weight per day for 17 days (51 mg per kg) or when the concentration in the brain homogenate reached 42.0 μg per g tissue (42 mg per kg). More recently, these workers[21] used much lower concentrations of methylmercury over longer periods of time in beagle dogs and miniature swines and demonstrated species difference. Pigs were shown to be much more sensitive than dogs. In behavioral experiments with pigeons, Evans and Kostyniak[22] observed gross symptoms 5 weeks after initiation of treatment at 2 mg per kg body weight five times a week (50 mg per kg). After 11 weeks of dosing at 1 mg per kg body weight (70 mg per kg), one of two pigeons developed gross symptoms but the other did not.

CONCLUSION

Our research has sufficiently demonstrated the high sensitivity of radiorespirometry, a technique that meets

requirements and possesses the advantages stated above. We believe that this type of approach will increase our ability to economically test various pollutants and substances for their toxicities.

REFERENCES

1. Wang, C. H. Radiorespirometry. Methods of Biochemical Analysis, XV:312-368, 1967.
2. Lee, S. D., Butler, K. C., Danner, R. M., McMillan, L., Moore, W., and Stara, J. F. Application of Radiorespirometry in the Study of Biological Effects of Environmental Pollutants. American Laboratory, December 1972.
3. Gould, R. G., Sinex, F. M., Rosenberg, I. N., Solomon, A. K., and Hastings, B. Excretion of Radioactive Carbon Dioxide by kats After Administration of Isotopic Bicarbonate, Acetate and Succinate. Biol. Chem. 17:295-301, 1948.
4. Tolbert, B. M., Hughes, A. M., Kirk, M. R., and Calvin, M. Effect of Coenzyme A on the Metabolic Oxidation of Labeled Fatty Acids: Rate Studies, Instrumentation and Liver Fractionation. Biochem. and Biophys. 60:301-319, 1956.
5. Tolbert, B. M., Kirk, M., and Baker, E. M. Continuous $C^{14}O_2$ and CO Excretion Studies in Experimental Animals. Amer. J. Physiol. 185:269-274, 1956.
6. Domingues, F. J., Gildner, K. J., Baldwin, R. R., and Lowry, J. R. An Instrument and Technique for the Continuous Measurement of Respiratory CO_2 Patterns in Metabolic Tracer Studies. Intern. J. Appl. Radiation and Isotopes, 7:77-86, 1959.
7. Dost, F. M., Reed, D. J., and Wang, C. H. The Metabolic Fate of Monomethylhydrazine and Unsymmetrical Dimethylhydrazine. Biochem. Pharmacol., 15:1325-1332, 1966.
8. Sato, K., Suzuki, R. and Tsuiki, S. Oxidation of 6-^{14}C glucose to $^{14}CO_2$ by the Pentose Cycle in Ehrlich Ascites Tumor Cells. Biochim. Biophys. Acta. 148:307-309, 1967.
9. Meek, J. L., Majchrowica, E., and Lipton, M. Rates of $C^{14}O_2$ Production from Labeled Ethanol, Acetate and Glucose in Alcohol Drinking and Non-drinking Rats. Proc. Soc. Exp. Biol. Med. 126(2):379-383, 1967.
10. Davidson, W. D., Arthur, M. D., Schwabe, D., Carols, A. E., Patton, J. J., and Thompson, J. C. Continuous Measurement of ^{14}C-Labeled Substrate Oxidation by Isolated Dog Gastric Mucosa: An Ionization Chamber Method. Surg. Forum 18:345-347, 1967.
11. Vann, L. S., Helwig, H. L., and Goetz, M. E. Carbon Tetrachloride Lowering of Choline Oxidation in Mice. A Radiorespirometric Study. Toxicol. Appl. Pharmacol. 14:457-468, 1969.
12. Malmendier, C. L., Delcroix, C., and Van Den Bergen, C. J. In vivo Demonstration of Differences in Substrate Oxidation in Normal and Nephrotic Rats. Am. J. Physiol. 218:911-918, 1970.
13. Liu, D. H. W., Kruger, H., and Wang, C. H. Catabolic Pathways for Glucose in the Cichlid Fish, *Cichlasoma bimaculatum*. Comp. Biochem. Physiol. 36:173-181, 1970.
14. Dost, F. M., Johnson, D. E., and Wang, C. H. Metabolic Effects of Monomethyl Hydrazine. Aerospace Medical Research Laboratory, Aerospace Medical Division Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, AMRL-TR-73-33, June 1973.
15. Dost, F. M., Reed, D. J., and Wang, C. H. Effects of Various Hydrazines upon the Metabolism of Gamma Aminobutyric Acid (GAEA)-1-^{14}C by Rats. Biochem. Pharmacol. 20:1702-1707, 1971.
16. Amdur, M. O., and Mead, J. A Method for Studying the Mechanical Properties of the Lungs of Unanesthetized Animals: Application to the Study of Respiratory Irritants. Proc. Third National Air Pollution Symposium, April 1955.
17. Lee, S. D., and Danner, R. M. Biological Effects of SO_2 Exposures on Guinea Pigs. Arch. Environ. Health 12:583-587, 1966.
18. Nielands, J. B., and Stumpf, P. K. Outline of Enzyme Chemistry. John Wiley and Sons, New York, 1958.
19. Ganther, H. E., Goudie, C., Sunde, M. L., Kopecky, M. J., Wagner, P., Oh, S. H., and Hoekstra, W. G. Selenium: Relation to Decreased Toxicity of Methylmercury Added to Diets Containing Tuna. Science 175:1122-1124, 1972.
20. Miller, E., Brodwer, J., Tanner, J. T., Friedman, M. H., Earl, F. L., and Van Loon, E. J. Methylmercury Toxicity in the CNS of the Dog. Fed. Proc. 31:1954, 1972.
21. Miller, E., Sapienza, P., Earl, F. L., Olivito, V. L., Michael, T. C., and Van Loon, E. J. Toxic Effects of Methylmercury in Beagle Dogs and Miniature Swine. Fed. Proc. 32(3):274, 1973.
22. Evans, H. L., and Kostyniak, P. J. Effects of Chronic Methylmercury on Behavior and Tissue Mercury Levels in the Pigeon. Fed. Proc. 31:1956, 1972.

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

ADVANCED WASTE TREATMENT RESEARCH

October 25, 1974

A SWIRL DEVICE FOR REGULATING AND CONCENTRATING COMBINED SEWER OVERFLOWS

Richard Field*

BACKGROUND

A combined sewer carries both stormwater and municipal sewage. During periods of wet weather, a regulator is required to separate the flow to prevent overloading the treatment plant. In usual practice, the combined sewage that cannot be accommodated by the downstream intercepting sewer or treatment plant is bypassed by the regulator directly to the receiving waters, resulting in heavy wet weather pollution loads. In the past, these regulating devices only divided the flow between the treatment plant and the overflow point to protect the plant.

In 1970 a U.S. Environmental Protection Agency (EPA) state-of-the-art report on combined sewer flow regulators suggested that a device that used circular flow patterns could regulate flow and also remove solids, thus providing a dual function at low cost in a facility of relatively small volume. This principle has been demonstrated in a modest way in Bristol, England. A full-scale investigation of the concept by the EPA has produced hydraulic and mathematical models that were used to design a full-scale prototype "swirl regulator/concentrator." This device should minimize the all-too-common faulty regulator problems and significantly reduce the amount of settleable and floatable solids in the overflow. This simple practical structure has the advantages of low capital cost, short detention time, and the absence of moving parts, which should reduce maintenance problems. Construction with inert materials, where possible, should limit corrosion. The device is also self-cleaning by virtue of its own flow patterns; the various traps and outlets are easily cleaned during low-flow periods.

*Mr. Field (a Sanitary Engineer with the Advanced Waste Treatment Research Laboratory of the National Environmental Research Center – Cincinnati) is Chief of the Storm and Combined Sewer Section in Edison, New Jersey (201-548-3347).

BASIC PRINCIPLE

The swirl device differs from a sedimentation tank in that it utilizes the differences in inertia between particles and liquid as well as gravitational forces to effect solids-liquid separation.

Combined sewage is introduced close to the bottom of a circular chamber in a direction that is perpendicular to the radius. The kinetic energy of the incoming sewage is guided by a vertical deflector that makes the flow take this "long path" around the chamber. This is the so-called primary current and is readily visible. In any flow around a bend, a secondary current is introduced to make the surface portion of the liquid flow outward from the center and the bottom portion flow toward the center. The secondary current that acts in the swirl device is similar to the current observed in rivers that makes the stream erode its outer bank and deposit sediment on its inner bank. This current is induced by the difference in the inertial forces on the particles of different altitudes in the radial plane. Because of the effects of boundary friction, the water near the surface flows faster than the water near the bottom. The secondary current carries solids to the center, just as a river deposits sediment on the inner bank. Thus, most of the settleable solids and grit that are forced down (by gravity) and outward toward the perimeter (by inertial force) are then swept by the secondary current to the foul (concentrate) outlet, through which they exit to the treatment plant. The larger volume of liquid, which should now be relatively clear of solids, is relieved of its floatable matter by a trap and passes over the circular overflow weir and plate for additional treatment or discharge directly to the receiving water.

GENERAL DESCRIPTION

A small swirl flow regulator/solids-liquid separator is shown in Figure 1. A demonstration swirl device in operation at Syracuse, New York, is 3.66 m (12 ft) in

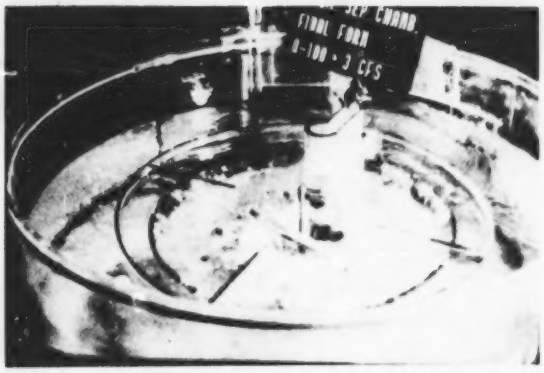

Figure 1. Overhead View of Swirl Flow Regulator/Solids Liquid Separator in Operation. Pilot Model at La Salle, P. Q., Canada.

diameter and 0.91 m (3 ft) to the top of the weir; its total cost is about $65,000. The design flow for this device is 3.29 x 10^4 cu m/day (8.7 mgd), which occurs about once every 5 years in the Syracuse area.

The swirl device regulates flows by a central circular weir, which is a modification of a common static flow regulator. During normal operation, it separates solids by means of the swirl action described above. Floatables are separated from the overflow by a trap located near the weir. During low dry weather flows, the sewage is guided along a groove in the bottom and goes directly to the interceptor, which conveys it to the treatment plant.

During higher-flow storm conditions, the low-volume, high-solids concentrate resulting from the swirl action is diverted via an outlet at the end of the bottom groove to the interceptor, and the clear, high-volume supernatant overflows the central circular weir. This liquid can be further treated and discharged into the receiving waters, or, depending on quality requirements, directly discharged into the receiving waters. Provisions can also be made for storage and subsequent pumping of this relatively clear liquid to the sanitary sewage treatment plant during low-flow, dry-weather periods. This method thus allows the maximum treatment possible but still protects the treatment plant from overloading. Such a system makes primary treatment possible at all times and prevents raw combined sewage from being passed directly to the receiving waters during periods of heavy flow.

SWIRL DESIGN CHARACTERISTICS

To be useful in coping with storm overflow pollution, this essentially static device must function under conditions of widely varying flow rates and solids contents. Thus the various elements of the chamber must be carefully designed. The isometric view of the swirl (Figure 2) may help to visualize the various special elements, which are identified by small letters.

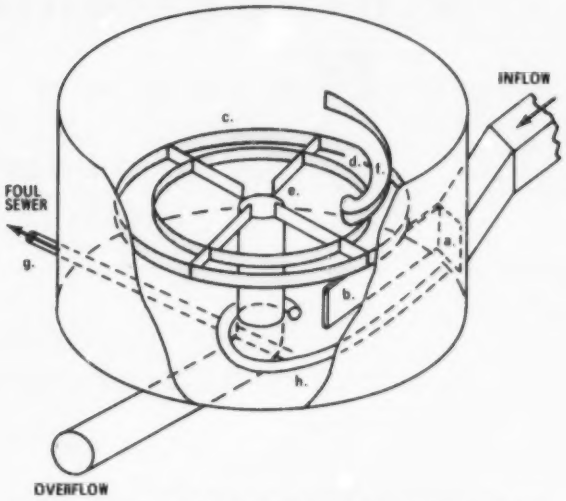

Figure 2. Isometric View of Swirl Regulator/Concentrator. Legend: a, Inlet Ramp; b, Flow Deflector; c, Scum Ring; d, Overflow Weir and Weir Plate; e, Spoilers; f, Floatables Trap; g, Foul Sewer Outlet; h, Floor Gutters.

Inlet Ramp

The inlet ramp introduces the incoming flow at the bottom of the chamber, thus allowing the solids a greater chance of being separated. Inflow should be nonturbulent to prevent the solids from being carried directly to the overflow weir along with the water. However, there should be enough energy to force the water around the chamber. The floor of the inlet ramp should be v-shaped to allow for self-cleaning during periods of low flow.

Flow Deflector

The flow deflector is a vertical, freestanding wall that is an extension of the interior wall of the inlet ramp. It directs the flow around the chamber, creating a longer path and a greater chance of solids separation.

Scum Ring

The scum ring prevents floating solids from overflowing. It should extend at least 15.2 cm (6 in.) below the level of the overflow weir crest and works by baffling floatables and preventing them from overflowing the weir until they reach the floatables trap.

Overflow Weir

The overflow weir and weir plate allow the liquid that has passed through the chamber and is now free of most of its settleable and floatable solids to leave the chamber through a central column and either be stored or bypassed to the river. The weir and its plate are designed to prevent floatables from overflowing with the supernatant.

Spoilers

The spoilers are radial flow guides that extend from the center shaft to the scum ring and are vertically

mounted on the weir plate. They allow efficient and controlled operation of the swirl concentrator under overload conditions and prevent turbulence and vortex conditions that impede proper functioning.

Floatables Trap

The floatables trap is a surface flow deflector that directs floatables under the weir plate for storage during wet-weather operation. When the liquid level in the chamber decreases after the rainfall, the floatables exit through the foul sewer outlet.

Foul Sewer Outlet

The foul sewer outlet, located on the floor of the chamber, is the orifice through which the dry-weather flow and storm-flow concentrate exit, via the interceptor, to the treatment plant. It is placed at the point of maximum settleable solids concentration and is designed to reduce the clogging problems that often incapacitate regulators.

Floor Gutter

The primary floor gutter is the peak dry-weather flow channel connecting the inlet ramp to the foul sewer outlet to avoid dry-weather solids deposition.

SOLIDS SEPARATION EFFICIENCIES

Actual combined sewage could not be used in the scaled-down hydraulic model that was constructed for initial testing of the swirl principle. Grit and settleable solids had to be simulated with gilsonite, a natural hydrocarbon that could be mathematically related to the various solids components. Floatables were simulated with pethrothene.

For a prototype, the predicted efficiencies were as follows:

- For floatables with a specific gravity range of 0.90-0.96 and particle sizes between 5 and 50 mm, the chamber should remove 65 to 80 percent.
- For grit with a specific gravity of 2.65 and particles larger than 0.3 mm, removal should be between 90 and 100 percent. Removal efficiencies decrease to about 75 percent for 0.2-mm particles and to less than 40 percent for 0.1-mm particles.
- For settleable solids with a specific gravity of 1.2 and particles larger than 1 mm, the efficiency should range from 80 to 100 percent. This fraction represents 65 percent of the total amount of settleable solids in the design solids concentration. For the finer particles, removal efficiencies decrease to about 30 percent for 0.5-mm particles and to less than 20 percent for 0.3-mm particles.
- The total suspended solids removal capability, including grit, should be about 65 percent.

The mathematical simulation of prototype efficiency indicated that the device will work well, up to 150 percent of design flow.

POTENTIAL USES

The swirl principle may be employed anywhere it is desirable to remove solid particles from liquid flows. In the field of water pollution control, this principle could relate to the degritting of sanitary and storm flows and to primary separation, sludge thickening, and the final clarification process. In potable water purification practices, it may be feasible to apply a form of the swirl for coagulation and clarification of raw water. Other possible uses include industrial processing and pollution control. These other applications may involve less arduous conditions of operation than does the combined sewer regulator application. Both the hydraulic laboratory and the mathematical model investigation have indicated that solids separation efficiency may increase if the device operates under steady flow conditions and if solids with a narrower range of size and specific gravity are to be removed.

Better efficiencies may also be achieved with two half-size chambers as opposed to one full-sized unit. With two units operating in parallel, one chamber could be used for all flows lower than a predetermined design value, and the second could be used if the storm flow exceeded that value. This approach would provide better separation at both higher and lower flow rates. Another possibility is operating the units in series to improve solids removal by breaking a wide range of particle characteristics into narrower grain size and specific gravity bands.

CONCLUSION

The dual-functioning swirl unit is the first regulator device of its type in this country to offer the basic advantage of simultaneously controlling the quantity and quality of combined sewer overflows. It is a simple and practical facility that can effectively reduce significant portions of grit, settleable solids, and floatables over a wide range of varying overflow rates.

BIBLIOGRAPHY

1. American Public Works Association. "Combined Sewer Regulator Overflow Facilities." U.S. Environmental Protection Agency, Edison, N.J. 11022 DMU 07/70. July 1970.
2. American Public Works Association. "The Swirl Concentrator As A Combined Sewer Overflow Regulator Facility." U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA-R2-72-008. September 1972.
3. Field, R. "The Dual Functioning Swirl Combined Sewer Overflow Regulator/Concentrator." U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA-670/2-73-059. September 1973.
4. Sullivan, R. H., et al. "The Swirl Concentrator As A Grit Separator Device." APWA. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA-670/2-74-026. June 1974.
5. Sullivan, R. H., et al. "Relationship Between Diameter and Heights For The Design Of A Swirl Concentrator As A Combined Sewer Overflow Regulator." APWA. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA-670/2-74-039. 1974.
6. Field, R. "Design of a Combined Sewer Overflow Regulator/Concentrator." Journal Water Pollution Control Federation, 46:1722-1741, July 1974.

NERC–Cincinnati's Recent Reports*

"Computer Management of a Combined Sewer System," EPA-670/2-74-022; also from NTIS† as PB 235 779/AS

"The Swirl Concentrator as a Grit Separator Device," EPA-670/2-74-026; also from NTIS as PB 223 964/AS

"Manual for Deicing Chemicals: Storage and Handling," EPA-670/2-74-033; also from NTIS as PB 236 152/AS

"Relationship Between Diameter and Height for the Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator," EPA-670/2-74-039; also from NTIS as PB 234 646/AS

"An Ion Exchange Process for Recovery of Chromate from Pigment Manufacturing," EPA-670/2-74-044; also from NTIS as PB 233 641/AS

"Microstraining and Disinfection of Combined Sewer Overflows – Phase III," EPA-670/2-74-049; also from NTIS as PB 235 771/AS

"Limestone and Limestone-Lime Neutralization of Acid Mine Drainage," EPA-670/2-74-051; also from NTIS as PB 234 607/AS

"Waste Oil Recycling and Disposal," EPA-670/2-74-052; also from NTIS as PB 235 857/AS

"Phosphate Removal in an Activated Sludge Facility," EPA-670/2-74-061; also from NTIS as PB 235 749/AS

"A Mathematical Analysis of the Kinetics of Viral Inactivation," EPA-670/2-74-067; also from NTIS as PB 235 124/AS

"Control Schemes for the Activated-Sludge Process," EPA-670/2-74-069; also from NTIS as PB 236 086/AS

NERC–Cincinnati's New Television Tapes/Films*

IMPROVED METHODS FOR DETERMINING THE ORGANICS IN DRINKING WATER
19 min., color, tape and film (16mm)

DETERMINATION OF ORGANICS IN DRINKING WATER
55 min., color, tape and film (16mm)

CAM–I (cholinesterase antagonist monitor)
10 min., color, tape

CHEMICAL AND PHYSICAL PROPERTIES OF OIL
26 min., color, tape and film (16mm)

THE USE OF GRANULAR ACTIVATED CARBON FOR WASTEWATER TREATMENT
Part I - 18 min., Part II - 17 min., black and white, tape

---

*Available from:
Technical Information Staff
National Environmental Research Center
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

†Available from:
National Technical Information Service
U.S. Department of Commerce
Springfield, Virginia 22151

☆ U.S. GOVERNMENT PRINTING OFFICE 1974— 657-051/1061

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency

WATER SUPPLY RESEARCH

November 11, 1974

RECREATIONAL WATER QUALITY CRITERIA

Victor J. Cabelli and Leland J. McCabe

INTRODUCTION

The recreational use of water takes many forms – from active contact with the water to enjoying vistas of large and small bodies of water. Stream standards must consider this beneficial use of water, and the U.S. Environmental Protection Agency (EPA) is currently developing criteria[1] for recreational water quality. The last criteria were promulgated in 1968,[2] and at that time, the need for research to provide supporting data was pointed out. The situation now is not much better, but at least, research is in progress that will eventually provide necessary data.

Belief in the germ theory leads to the conclusion that direct contact with polluted water should result in illness. But when the amount of swimming done by the American public, the extent of polluted beaches and old swimming holes, and the paucity of illness related to water contact are considered, one begins to wonder if there really is a cause and effect relationship.

The stream standards adopted to protect the recreational use of water can have a great effect on sewage treatment cost and the techniques used to control storm water runoff. The disinfection unit process, with its possible adverse ecological effects, is primarily done to protect the health of persons who use our surface waters for recreation. (A major exception would be the disinfection of discharges into estuaries to protect commercial shellfish growing areas.) If contact with water during recreation does not result in a major public health problem, it at least presents a major need for health effects research to define the criteria used in deciding how clean must water be to prevent illness.

PREVIOUS STUDIES

The research on this problem conducted by the National Environmental Research Center – Cincinnati builds on studies conducted by a predecessor organization in Cincinnati. In the early 1950's, the Robert A. Taft Sanitary Engineering Center conducted three studies of bathing water quality and health. In Stevenson's review[3] of these studies, he concluded that "... sufficient evidence is available to indicate that some of the strictest bacterial quality requirements for natural bathing water now existent might be relaxed without significant detrimental effect on the health of the bathers." Today many beaches are closed on coastal waters and large lakes adjacent to large population centers where swimming could be a major source of recreational activity.

Figure 1 diagrams the relationships eventually needed to make rational decisions on water quality standards. The problem is made complex by the occurrence of background illness, or the normally occurring illness rate of every population, which may be cyclic. When a person immerses himself in water, his chances of contracting illness increase, regardless of water quality.[3] Most persons accept this increased rate of background illness because of the benefits derived from swimming. An additional risk is posed by the fact that all surface water contains some microorganisms that cause illness. The additional risk can be minimum – the smallest increase that can be measured by available health effects research techniques. Or the risk can be great, with a large increase in illness that will be accepted by the population because no other water sites are available and additional water pollution control costs are deemed exorbitant. There are undoubtedly occasions when the trade-off will be made between bathing beaches and swimming pools.

These problems were studied in England[4] more recently, and working from available morbidity statistics, it was concluded that unless there were large visible fecal aggregates in the water, there was little risk to the health of bathers.

ENVIRONMENTAL PROTECTION AGENCY PROGRAM

Responding to the needs stated above, EPA initiated a research program in 1972 to provide the data base required for the development of recreational water quality criteria. The program has three basic tenets: (1) not only the numerical value but, more important, the

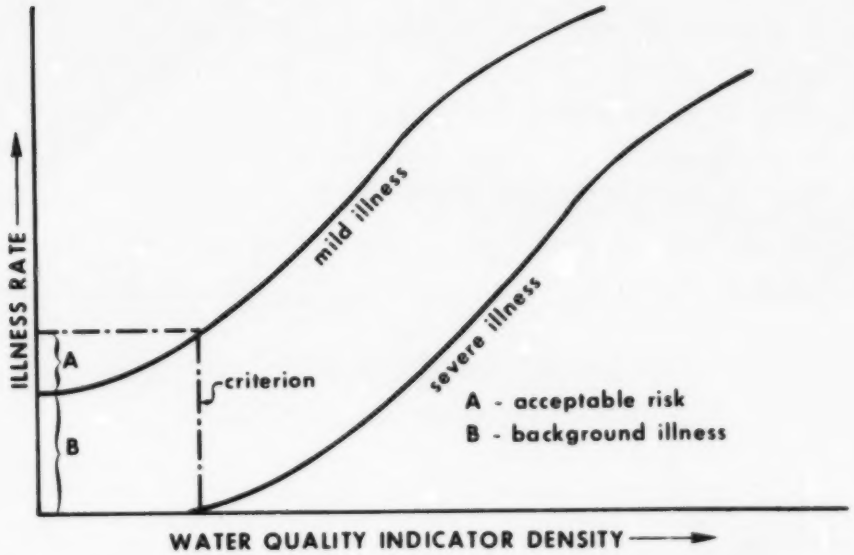

Figure 1. A hypothetical water quality criterion for recreational waters. The illness rates may be expressed by type (respiratory, gastrointestinal, etc.) for mild and severe cases (stomachache, restricted activity, or required medical care). The water quality can be measured by indicator organisms and density of specific pathogens.

appropriate indicators of recreational water quality are to be treated as unknowns; (2) the design of the program will be minimally, if at all, influenced by existing criteria at the local, state, and national levels; and (3) Stevenson's basic approach is the one most likely to provide the needed data.

Central to the EPA program are epidemiological-microbiological trials whose objective is to determine whether the incidence of illness among swimmers relative to nonswimming (but beach-going) controls can be correlated to some microbial or chemical indicator(s) of water quality.

An analysis of Stevenson's studies revealed several design features that may have precluded obtaining definitive results. Inconclusive results were due largely to the use of the "calendar" approach, in which study families kept a record of all their swimming activity and illnesses. The current study uses a more rigorous definition of swimming, and immersion must occur to be sure that a real exposure has taken place. The followup eliminates multiple days of exposure by using only persons who swim at the study beaches on Saturday or Sunday. A nonswimming control is provided by obtaining data from persons at the beach who are not swimming but engaging in the other activities at the location that could influence illness rates. The sequence of events during a typical weekend pair of trials is shown in Table 1.

The consequences of the decision to treat the identity of the "correct" indicator(s) of water quality as unknowns are (a) that the epidemiological data will be used in defining the correct water quality indicator(s) and,

TABLE 1. SEQUENCE OF EVENTS FOR EPIDEMIOLOGICAL-MICROBIOLOGICAL TRIALS

Day of week	Day number	Activity	Function
Saturday	1	(Beach interview, water sampling)	(a) Obtain name, address, phone, etc. (b) Reject pretrial midweek swimmers (c) Query on beach activity (d) Assay of water samples
Sunday	2	(Beach interview, water sampling)	As above
Monday	3	Reminder letter	(a) Provide name of physician (b) Reminder to note illness
Monday	10	Phone or mail interview	(a) Obtain illness information (b) Reject post-trial midweek swimmers (c) Obtain demographic information

therefore, (b) that the water will be quantitatively examined for a rather large number of potential indicators of water quality. These decisions required that a major effort be directed towards evaluating and, as required, developing enumerative methods for a number of microbial pathogens and "indicators" deposited into or indigenous to the marine waters at the test beaches. The status of this effort is presented in Table 2.

TABLE 2. SOURCE, ROLE, AND STATUS OF ENUMERATION METHODOLOGY FOR CANDIDATE HEALTH EFFECTS INDICATORS

Organism	Significant source*	Possible role†	Methods development‡
Enteroviruses	F S	P	U
Salmonella	F S	P	D(S-HVS)
Shigella	F S	P	Z
P. aeruginosa	S I R A	P	D(mPA)
A. hydrophila	S R A	P	D(mA)
Coliforms	F S I R A	W§	D(TC MPN),(mC)
E. coli	F	P W	D(mC)
Klebsiella	F S I R A	P W N	D(mC),(mK)
Enterobacter	S I R A		D(mC)
Citrobacter	R A		D(mC)
Fecal coliforms	F S I	W	D(EC MPN),(mC)
Fecal streptococci	F S R	W	D(mSD)
V. parahemolyticus	A	P¶ N	U
C. perfringens	F S	W	U
C. albicans	F S¶	P W	Z

*Relative to other sources: F, feces of warm-blooded animals; S, sewage; I, industrial wastes; R, runoff from uncontaminated soils; A, estuarine or coastal waters.

†Role: P, pathogen; W, indicator of sanitary wastes; N, indicator of nutrient pollution.

‡Status of method (quantitative development): D, developed; U, under development; Z, no method. These are existing methods or methods under development for these organisms. The m indicates a membrane filter method, MPN a multiple tube method, and the HVS a high volume sampling method.

§Questionable.

¶Insufficient information.

Bathing beaches in the vicinity of New York City were chosen for the "temperate zone" study. Tentatively, the beach areas in the vicinity of 24th Street at Coney Island were selected as the "barely acceptable" (BA) beach, and those around 67th Street at the Rockaways as the "relatively unpolluted" (RU) beach. Available data indicated that, irrespective of the tidal situation, there was at least one order of magnitude difference in the total coliform (TC) levels at the BA as compared with the RU beach.

Data collected during the summer of 1972 (a) demonstrated that the populations at the two beaches were demographically comparable within the limits required for this study, (b) showed that the subjects are reasonably accurate in their reporting of the nature (though not necessarily the duration) of their bathing experience, (c) indicated that an acceptable level of cooperation could be expected from the participants during beach interviews and followup phone questionnaires, and (d) confirmed the differences in total coliform levels at the BA and RU beaches.

METHODOLOGY PRETEST, 1973

In cooperation with Mr. Paul Haberman of the Center for Policy Research, New York City, New York, a pretest of the epidemiological and microbiological methodology was completed during the summer of 1973. The details of this phase of the overall program are being prepared for publication (Cabelli et al., 1974).[5]

The results from eight trials, conducted according to the scheme given in Table 1, leave little doubt that both the epidemiological and the microbiological methodology will be appropriate for the second phase of this study.

With the exception of *A. hydrophila* and possibly fecal streptococci, the differences between the two beaches with respect to the densities of the candidate health effects indicators were both significant and appreciable (Table 3), in spite of within- and between-trial variability. During the trials, the Coney Island beach did meet the National Technical Advisory Committee's recreational water requirement that the fecal coliform density not exceed a log mean of 200 per 100 ml. However, more than 10 percent of the samples had a fecal coliform density in excess of 400 per 100 ml, the second aspect of the criterion.

TABLE 3. COMPARISON OF INDICATOR AND PATHOGEN DENSITIES AT THE "BARELY ACCEPTABLE" AND "RELATIVELY UNPOLLUTED" BEACHES

Organisms	Method*	Log mean recovery/100 ml	
		Coney Island (20th St.)	Rockaways (67th St.)
Total coliforms	mC	983†	39.8
Fecal coliforms	mC	165†	21.5
E. coli	mC	174†	24.8
Klebsiella	mC	122†	13.7
Enterobacter	mC	530†	11.1
Fecal streptococci	mSD	91.2	21.8
P. aeruginosa	mPA	30.4†	6.5
A. hydrophila	mA	25.3	26.5

*These are membrane filter methods developed for the organisms listed and carry the abbreviated designation to distinguish from densities determined by other methodologies.

†Significantly different at 95 percent confidence level.

The epidemiological findings confirmed Stevenson's (1953)[3] observation that the overall illness rate was higher among swimmers than nonswimmers. When the symptoms were categorized as gastrointestinal, respiratory, other, and severe and when the rates among nonswimmers were subtracted from those among swimmers, the rate at the BA beach was higher than that at the RU beach for all illness categories except respiratory (Table 4). A statistical analysis of these data revealed that the incidence of gastrointestinal symptoms

TABLE 4. ILLNESS RATES BY TYPES AT CONEY ISLAND AND ROCKAWAYS BEACHES*

Illness category	Illness rate (%)	
	Coney Island	Rockaways
Respiratory	2.7	6.3
Gastrointestinal	4.8	3.5
Other	3.3	0.5
Severe symptom(s) (incapacitating or relatively serious)	1.7	0.4

*Values given are the rates for swimmers less the rates for nonswimmers.

among swimmers was significantly higher than that among the nonswimming controls at the BA beach, but not at the RU beach. An identical analysis of the data for respiratory illnesses revealed a significantly higher rate among swimmers than nonswimmers at the RU beach, but not at the BA beach (a possible explanation involving differences in surf activity is presented in the report to be published[5]).

These findings must be considered preliminary in view of the relatively small numbers of individuals queried during the pretest and the lack of repetition (the data for all eight trials were used in the analysis). They do, however, reinforce the expectation that significant findings can be expected in the studies to be conducted at these sites during the summers of 1974 and 1975. Each weekend trial will include a study population as large as the total 1973 pretest.

Organizational changes dictate a restructuring of this research. Dr. Cabelli will continue in immediate charge of the research on criteria for recreational marine water, and his group has become part of the National Marine Water Quality Laboratory, Narragansett, Rhode Island of NERC-Corvallis. Mr. McCabe of NERC-Cincinnati will be in charge of research on recreational fresh water criteria; research emphasis in the next year will be on amebic meningo-encephalitis.

REFERENCES

1. U.S. Environmental Protection Agency. 1973. Proposed water quality criteria. Washington, D.C.
2. Report of the Committee on Water Quality Criteria. 1968. U.S. Department of the Interior, Federal Water Pollution Control Administration. Washington, D.C.
3. Stevenson, A. H. 1953. Studies of bathing water quality and health. J. Am. Publ. Hlth. Assn. 43:529.
4. Moore, B. 1959. Sewage contamination of coastal bathing waters in England and Wales: A bacteriological and epidemiological study. J. Hyg. 57:435.
5. Cabelli, V. J., P. W. Haberman, M. A. Levin, L. J. McCabe, and A. P. Dufour. 1973. Recreational water quality criteria: I. Pretest of epidemiological and microbiological methodology. (To be published.)

☆ U.S. GOVERNMENT PRINTING OFFICE 1974— 657-052/1069

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA 335

News of Environmental Research in Cincinnati

U.S. Environmental Protection Agency

ADVANCED WASTE TREATMENT RESEARCH

December 13, 1974

GRANULAR MEDIA FILTRATION OF SECONDARY EFFLUENT

James F. Kreissl*

Filtration of effluents from biological treatment plants has been practiced for decades in some areas of the world (primarily Great Britain), but the use of granular media filters in wastewater treatment is relatively new to the United States. With the new and more stringent effluent standards in this country, interest in wastewater filtration has increased dramatically. Unfortunately, information on good design and operation of filtration systems in wastewater treatment is rather sparse and inconsistent.

APPLICATIONS OF FILTRATION

The primary applications of filtration in waste treatment are direct filtration of secondary effluent, filtration of chemically clarified secondary effluent, and filtration of chemically clarified raw wastewaters. This discussion is concerned only with the direct filtration of secondary effluent, because this application is the most likely to be used in the near future when plants will be required to consistently meet better effluent quality standards than they are presently able to attain.

Obviously, filtration will not always be the answer to all such situations. The need for intelligent engineering judgment in each situation is axiomatic. Factors that must be taken into account when considering the applicability of filtration to any wastewater treatment plant are the feasibility of in-plant modifications, the difference between present effluent quality and required standards for all pollutants, and the relative costs of alternative solutions. For example, if a plant with an effluent of 40 mg per liter of biochemical oxygen demand (BOD) and suspended solids (SS) were required to meet a 25:25 standard, it could not be assumed that direct filtration would necessarily achieve the required effluent quality. If, however, it were determined that the soluble fraction of the BOD was small in relation to the total concentration, removal of SS by filtration would certainly appear to be a likely process for that particular situation. This example ignores such requirements as phosphorus, ammonia, or total nitrogen removal, which may significantly affect the overall plant design.

*Mr. Kreissl is a Sanitary Engineer with the National Environmental Research Center – Cincinnati (513-684-8304).

DESIGN CONSIDERATIONS

Major Design Goals

When designing filters for direct filtration of secondary effluent, the major goals are (1) attainment of required effluent, (2) low capital cost, and (3) low operating cost.

The first goal is obvious; if effluent quality requirements cannot be met, the design is a failure. For any particular filter design, low capital cost can be primarily correlated with reduced land requirements and high filtration rates. Low operating costs can be roughly related to reduced frequency of backwashing or higher production per filter run. (Production is the average filtration rate times the length of run or the gallons filtered per unit area during a filter run.) In essence, the optimum filter would produce the most effluent at the highest rate while meeting the effluent quality objectives.

Pilot Plant Studies

Despite the widely varying opinions found in the wastewater filtration literature, a few areas of agreement are apparent. One is the need to perform pilot plant studies in order to properly design wastewater filters. One investigator[1] has suggested 12 months of pilot plant operation; this would be the ideal rather than the practical solution, but significant information for all four seasons, or at least for the most critical period, would be desirable. The critical periods can probably be judged best after studying the operating records of previous years.

Preceding Treatment Systems

The single most important factor affecting filter performance is the preceding wastewater treatment. If consistently good performance is exhibited by the biological treatment system ahead of the filter, good filter performance can be expected. Conversely, if the biological facility is subject to frequent upsets, filtration will be much more difficult during those periods. The need for extensive pilot plant studies intensifies with such a facility. The causes of these upsets should be considered before designing a tertiary filter for such a

facility, since the filter does not represent a panacea for all treatment shortcomings.

MAJOR VARIABLES AFFECTING FILTER PERFORMANCE

The primary variables commonly mentioned in reference to filtration can be grouped into three categories: influent solids characteristics, liquid characteristics, and physical characteristics of the filter media.

Influent Solids Characteristics

The most important variable affecting filter performance is the influent solids characteristics: their physical and chemical nature as well as their concentration. As indicated previously, the pretreatment ahead of the filters is the primary determinant of filter performance. Pretreatment dramatically influences the characteristics of influent solids, especially their chemical and physical makeup. The fact that no universally reliable measure of the filterability of different types of solids exists establishes the need to have pilot studies for each potential filter application. There are, however, certain established variables used for characterizing the biological treatment operation that do relate to the solids of these systems. These variables include the sludge-volume index (SVI), the food-to-microorganism ratio (F/M), and the solids retention time (SRT).

Sludge-Volume Index

Although the sludge-volume index (SVI) is generally unrelated to effluent SS concentration, it does represent a surface property of the solids, i.e., the resistance of the solids to thickening. A comparative study of a dual- and multi-media filter at the U.S. Environmental Protection Agency (EPA), Blue Plains Pilot Plant in Washington, D.C.,[2] indicated that effluent SS concentrations generally increased when SVI increased. The SS in the effluent of the dual-media filter increased more rapidly at higher SVI values, owing to the absence of fine grain sizes (garnet) contained in the multi-media design.

Food-to-Microorganism Ratio

The food-to-microorganism (F/M) ratio is a measure of the organic loading on a biological treatment system. Low F/M ratios indicate lightly loaded systems, e.g., extended aeration. High F/M ratios are common to high-rate systems, e.g., contact stabilization. Although F/M ratios are not normally used in connection with trickling filters, a high-rate trickling filter would have a higher F/M ratio than a low-rate system, e.g., two-stage. The relationship between the F/M ratio and the expected SS concentration of the granular media filter effluent is shown in Table 1.[3] Since the SRT is inversely related to the F/M ratio, high SRT values correspond to low F/M ratios. Relative values of each of these parameters are shown in the table. Trickling filter effluent is considered by many investigators to be more difficult to filter than activated sludge effluent.[3-5]

Liquid Characteristics

The effect of filtration rate on effluent quality is secondary to the effect of influent solids; however, its importance can be great under certain circumstances. When influent solids concentrations are reasonably low (below approximately 35 mg per liter), the effect of filtration rates up to 407 liters per min per sq m (10 gpm per sq ft) on effluent quality is relatively insignificant.[1,6,7] However, when influent solids are high (usually a sign of a malfunctioning plant), the effluent quality has been shown to degrade with filtration rates above about 204 liters per min per sq m (5 gpm per sq ft). Winter temperatures will also accentuate the effects of filtration rate since higher viscosities at low temperatures tend to drive particulate matter deeper into the filter.

TABLE 1. EXPECTED SS CONCENTRATIONS FROM FILTRATION OF SECONDARY EFFLUENTS*

Effluent type	F/M	SRT	SS (mg/l)
Trickling filter			
high-rate	high	low	10-20
two-stage	low	high	6-16
Activated sludge			
contact stabilization	high	low	6-15
conventional	medium	medium	3-10
extended aeration	low	high	1-5

*Source: Culp, R. L., and Culp, G. L., Advanced Wastewater Treatment, Van Nostrand Reinhold Co., New York 1971.

Physical Characteristics of the Media

The effect of media design on filter effluent quality is also less important than the influent solids characteristics. Although many investigators have attempted to perform comparative design studies, few significant design advantages have been satisfactorily demonstrated.[1,2,8,9] Some studies have shown that dual-media and multi-media as well as upflow filter designs are superior to classical sand filters from the standpoint of increased production and longer runs; but the relative advantage of any one of these systems over the others is less clear.[2,8,9] The advantage of these designs is based on the coarse-to-fine principle of filtration, which provides for removal throughout the filter bed and protection of the finer grains from excessive solids loadings that result in undesirably short runs. Other unique approaches to accomplishing high levels of production have been reported.[10-12]

SUMMARY OF APPLICABLE DATA ON DIRECT FILTRATION OF SECONDARY EFFLUENTS

Most of the applicable data from the references are gathered into a single plot of influent solids versus effluent solids in Figure 1. The results indicate that when influent SS are below approximately 35 mg per liter, roughly 70 percent of those solids are removed. The dotted lines indicate the approximate upper and lower limits (a minimum removal of 50 percent and maximum of 90 percent). It should be noted that these data include activated-sludge as well as trickling filter plants, high and low filtration rates, and various media designs.

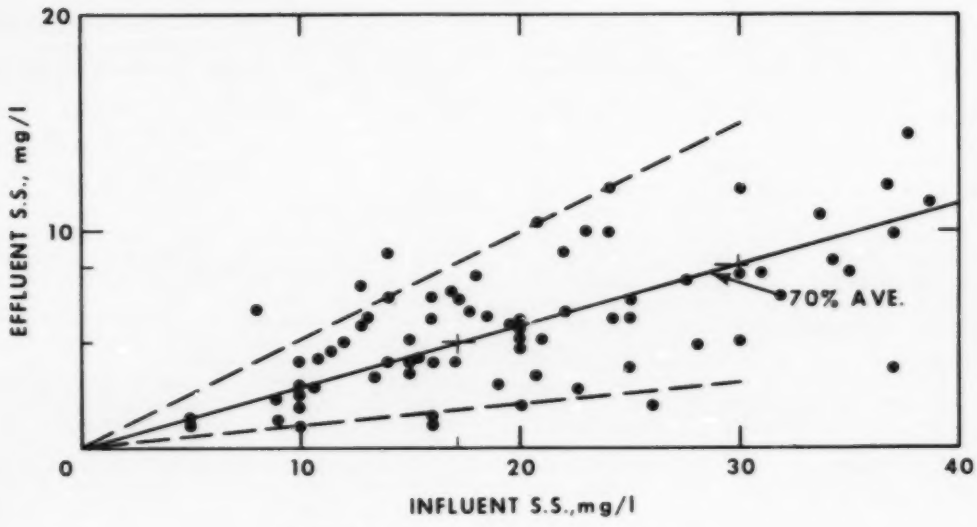

Figure 1. Secondary effluent filtration summary.

The usefulness of Figure 1 for estimating the potential of tertiary filtration of a given secondary effluent can be seen readily. For instance, if a plant meets the EPA definition for secondary treatment[13] (i.e., SS and BOD of 30 mg per liter), tertiary filtration should provide an effluent with a SS concentration of about 10 mg per liter. The effluent BOD would be a function of the solids makeup, but could probably be expected to be at least halved. If an effluent solids concentration of 5 mg per liter were required, a filter influent SS of about 16 mg per liter would probably be necessary to meet this requirement.

Although this information is helpful, it does not suffice for the proper design of secondary effluent filters for a specific application. Data such as those illustrated in Figure 2 are needed to formulate a rational design. This figure represents the results of pilot plant studies – results presented in a manner that can be used by the designer to predict the probable performance of the full-scale filter during the critical operational periods that will be encountered.

BACKWASHING

The most important fact evident in all the backwashing information available in the literature is that some form of auxiliary wash is absolutely necessary for any wastewater filter owing to the nature of the wastewater, i.e., the tendency to produce tenacious biological growths on the media surfaces. Some investigators favor surface washing, whereas others prefer air washing in addition to the normal backwash flow.[3,14-16] The relative merits of these two auxiliary washing systems are likely to vary with media designs, but present knowledge is insufficient to make quantitative judgments. Some investigators have noted difficulties with air washing when using lighter media such as coal or activated carbon;[3,14] another has indicated that air provides a more complete scouring of the filter bed than the limited action of a surface washing device.[15] Further information on this subject is being obtained through a research project at Iowa State University, sponsored by EPA.

In general, filter backwash rates for sand, dual-media, and multi-media filters vary between 610 and 814 liter per min per sq m (15 and 20 gpm per sq ft) for 5 to 10 min duration. There are exceptions to these ranges for different filter designs, such as shallow sand beds, deep

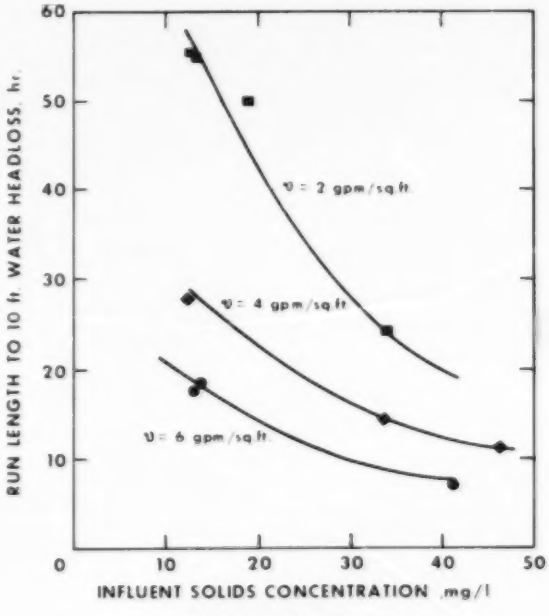

Figure 2. Design data.

beds of one or more types of media, and continuous filter systems. The recycling of spent filter backwash water can be highly disruptive to the entire treatment facility without adequate control provisions. For example, if a waste treatment facility employed two filters at a filtration rate of 203.5 liters per min per sq m (5 gpm per sq ft), backwashing one of the filters at 814 liters per min per sq m (20 gpm per sq ft) would produce a surge of about 3 times the normal or design flow for the duration of the backwash if the spent washwater were returned directly to the plant. The need for flow equalization, holding tanks, or separate treatment of these streams is obvious, and designers must give proper consideration to the available alternatives.

CONCLUSION

More information on wastewater filtration is needed before the process can be applied in an optimum manner. Although a reasonable number of studies have been reported in the literature, few areas of agreement are set forth in a usable form for the engineering community.

REFERENCES

1. Tebbutt, T. H. Y. An Investigation into Tertiary Treatment by Rapid Filtration. Water Research (G.B.), 5:81, January 1971.
2. Bishop, D. F., Jr. Internal Monthly Reports, Blue Plains Pilot Plant, EPA, Washington, D.C. 1972.
3. Culp, R. L., and Culp, G. L. Advanced Wastewater Treatment. Van Nostrand Reinhold Co. New York, 1971.
4. Goodman, B. Advanced Wastewater Treatment Methods. Ecodyne Corp. Smith & Loveless Division. 32 pages
5. Evers, R. H. Tool Up With Mixed-Media Filters. Water & Wastes Engineering 8:5, C-14, May 1971.
6. Misaka, Y., and Polkowski, L. B. Filtration of Activated Sludge Secondary Effluents through Sand and Anthracite-Sand Beds. Technical Report #OWRR A-D06-Wis (3), University of Wisconsin Water Resources Center, June 1969.
7. Michaelson, A. P. Under the Solids Limit at Ashton-under-Lyne. Water Pollution Control (G.B.), 70:533, 1971.
8. Zenz, D. R., Lue-Hing, C., and Obayashi, A. Preliminary Report on Hanover Park Experimental Bay Project. EPA Grant WPRD 92-01-68(R2), Project No. 11010 EZJ, November 1972.
9. Oakley, H. R., and Cripps, T. British Practice in the Tertiary Treatment of Wastewater. Journal Water Pollution Control Federation, 41:36, January 1969.
10. Nebolsine, R., Harvey, P., and Fan, C. Y. High-Rate Filtration of Combined Sewer Overflows. USEPA Water Pollution Control Research Series No. 11023 EYI, April 1972; NTIS, PB 211 144.
11. Effluent Polishing with Deep-Bed Filtration. Dravo Technical Bulletin No. 7/WWT 19.
12. Rogers, E. E. Operation Reports for Green Meadows II Sewage Treatment Plant, 1971.
13. Secondary Treatment Information. Federal Register, 38:82, 10615, April 30, 1973.
14. Guiver, K., and Huntingdon, R. A Scheme for Providing Industrial Water Supplies by the Re-Use of Sewage Effluent. Water Pollution Control (G.B.), 70:75, 1971.
15. Dvorin, R. Advances Make Wastewater Filtration Economical and Effective Solution. Water and Sewage Works, 116:9, 1W/12, September 1969.
16. Radziul, J. V., and Hess, A. High-Rate Filtration: What Needs to be Done? Water and Wastes Engineering, 8:5, 52, May 1971.

☆ U.S. GOVERNMENT PRINTING OFFICE 1974— 657-053/1078

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S. MAIL

News of Environmental Research in Cincinnati
U.S. Environmental Protection Agency
INDUSTRIAL WASTE TREATMENT RESEARCH
December 27, 1974

COAL REFUSE DISPOSAL IN THE EASTERN UNITED STATES

John F. Martin*

COAL AND ITS MINING

Solid wastes and impurities removed from coal by washing and preparation are defined as refuse. Waste coal, rock, pyrite, and other reject materials separated during the underground mining process are gob. The mining, crushing, and washing processes are designed to concentrate these impurities in the refuse and gob so that the marketable coal is relatively pure.

A study of the geologic formation of coal is the first step in understanding the composition of refuse and in disposing of it in an environmentally safe manner.[1] Swamps of the Mesozoic and Paleozoic eras account for most of the Earth's coal reserves. Vegetable material falls into the swamp, is protected from immediate decay by the high water table, and begins to accumulate and form a peat bog. Natural acidity in the vegetation is probably responsible in part for the depressed rate of biological decomposition. In the absence of erosive forces, the bogs are filled, eventually covered by protective layers of sediment, and slowly converted to lignite, bituminous, and anthracite coals.

The conditions required for coal formation are: an interior or coastal swamp environment, little erosion, rapid deposition of material, and subsidence or subsequent flooding to allow further deposition and covering. Considering this type of formation, one can easily visualize layers of silt and other foreign matter periodically flooding into the swamp, covering the vegetable material, and eventually forming partings in the fully developed coal seam.

The vegetable material carries with it various minerals and trace metals accumulated during the growth process. Among these constituents is organic sulfur derived from the swamp water. Studies show that sulfur and pyrite are present in modern peat deposits, as they must have been in the geologic past. According to Simon and Hopkins,[1] seawater in the coastal swamps may have been a primary contributor of sulfur in the form of lenses, nodules, and bands in the coal seam and adjacent strata. In addition to the impurities formed in the coal during its deposition, mineral impurities are carried by the groundwater into the porous layers of fully formed coal seams.

In 1971, the United States produced 501 million t (550 million short tons) of lignite and bituminous coal through combinations of surface, auger, and underground mining.[2] Pennsylvania anthracite accounted for an additional 7.9 million t (8.7 million short tons). Mechanical cleaning of the lignite and bituminous coal was required for 49 percent or 246 million t (271 million short tons). Refuse from this operation totaled 81 million t (89 million short tons).

Approximately 50 percent of the domestic lignite and bituminous coal produced in 1971 was the result of underground operations. Seventy percent of the underground coal required cleaning, as opposed to only 30 percent of the surface mined coal. The larger portion of refuse produced was not near a surface pit where it could be easily buried and waste piles resulted. West Virginia contained the largest number of coal cleaning plants, and according to the 1971 statistics,[2] the largest amount of refuse from mechanical cleaning was produced there.

From 1967 through 1971, the total U.S. production of lignite and bituminous coal remained fairly constant. During this same period, the percentage of mechanically cleaned coal dropped steadily, from 63.2 to 49.1 percent. This reduction is in large part due to the shifting emphasis now given to surface mining. The result has been a decrease in refuse production. Washing of all coals, however, is becoming more important as environmental concern increases.[3]

THE POLLUTION COAL REFUSE CAN CAUSE

The coal refuse disposal problem bears equally on air pollution, water pollution, and land use. In addition, the refuse disposal site is often considered aesthetically offensive.

A loosely packed refuse pile that is high in combustible material is a prime candidate for spontaneous ignition (Figure 1). Once on fire, a refuse pile is extremely difficult and dangerous to quench. The resulting fumes are high in sulfur oxides and present a serious health hazard to those living nearby. A recent

*Mr. Martin (513-684-4417) is a Civil Engineer with the National Environmental Research Center – Cincinnati.

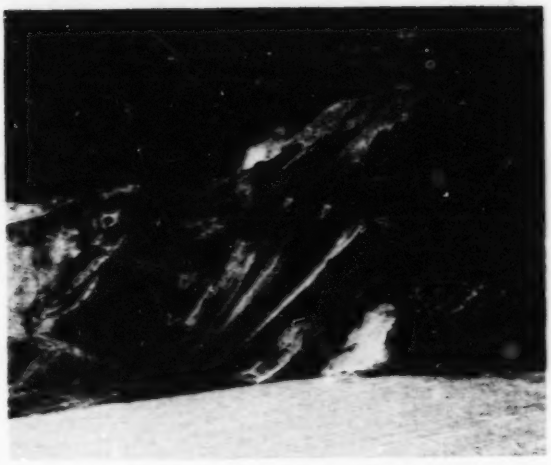

Figure 1. Hillside dump that has partially burned. Note the smoke in the center, indicating an active fire.

survey of active refuse piles in Pennsylvania indicates signs of fire in 29 of the first 135 piles visited. In addition to fumes from refuse fires, fine refuse particles carried by the wind are a source of considerable dust.

Water pollution from refuse has basically two forms: acid drainage and siltation. The acid mine drainage formed by refuse varies with the location, seam mined, compaction, cover material, etc. Siltation is directly influenced by the steepness, compaction, drainage control structures, and cover material of the pile (Figure 2). In portions of eastern Kentucky, Indiana, and Illinois, however, acid formation appears to be the worst. The water quality information in Table 1, obtained from single grab samples taken in April and May 1974, illustrates the extreme variability of effluent from refuse.

Although not directly dependent on acidity, the solubility of metals varies with pH and results in high metal ion loads in the more acid waters.

TABLE 1. WATER QUALITY DATA FROM SELECTED REFUSE SITES

Parameter	Luzerne County, Penna.	Pike County, Ky.	Muhlenburg County, Ky.	Sullivan County, Ind.
pH	3.0	6.9	2.5	2.4
Conductivity*	4400	880	6800	6400
Acidity†	690	7	7020	6500
Alkalinity	–	135	–	–
SO_4	3000	690	7800	9500
Na	100	115	270	200
Mg	250	26	195	285
Al	87	1.8	440	340
K	4.8	8.1	13	3.0
Ca	340	50	300	350
Mn	50	3.5	72	120
Fe	30	6.2	3400	2600
Ni	1.7	–	3.0	1.6
Cu	0.14	–	–	0.16
Zn	2.8	0.1	8	7.2
Pb	–	–	0.12	0.30

*All values expressed in mg/l except pH in standard units and conductivity in umhos/cm.

†Acidity to pH 7.3.

WHAT'S BEING DONE TO REDUCE OR PREVENT THIS POLLUTION

The culm bank, refuse pile, or waste heap was, in the early mining days, the easiest spot for random dumping. It may have been adjacent to the preparation plant, over the nearest hillside, or in a stream bed. Our failure to properly plan and engineer these waste sites has caused many of them to be environmental hazards. Loosely deposited materials may burn, leach polluted water, and erode extensively. Today, the careful construction of refuse piles is essential (Figure 3).

Various methods are employed to transport material to the waste dump.[4,5] Each system is designed to take advantage of the terrain and to apply to the type and quantity of refuse produced. The most popular haulage method today is by truck. It is essential that a dozer complement the trucks by keeping the disposal site well

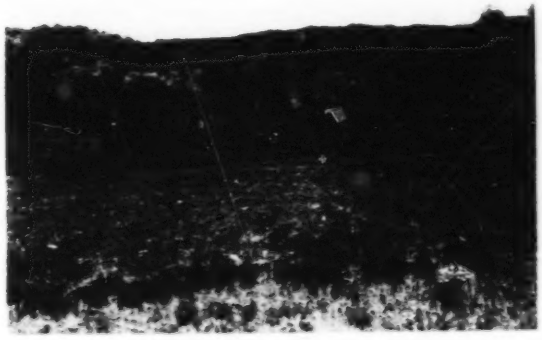

Figure 2. Highly eroded side slope of refuse pile.

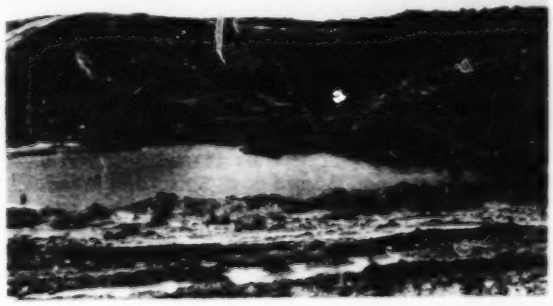

Figure 3. Burial of refuse material in a western Kentucky strip pit before leveling and revegetating.

shaped and compacted. A sheeps-foot roller greatly increases the effectiveness of the dozer in compacting thin layers. On many active disposal sites, the truck drivers are encouraged to drive to the dumping location on a slightly different course each trip to aid in compaction. Pans or scrapers are also beginning to see service on the refuse disposal site to haul material, to spread the refuse accurately in thin layers, to form the pile, and to compact it.

The aerial tram is a popular haulage tool in mountainous regions, but it does a rather poor job of forming a stable pile. As the material drops, it tends to segregate into course and fine fractions. The side slopes rest at a steep natural angle, and there is relatively no compaction. A dozer used with a tram is helpful in building the pile, but it accomplishes less compaction than when used on truck-dumped waste. Belt haulage also requires some type of ground machinery to spread and compact material. Many of the huge anthracite culm banks were formed by dumping material over the edge of the pile and raising the road or mine car tracks as the pile grew. Often the piles burned because of their porous structures and low density. Riddled by erosion, the piles polluted the surface drainage with silt. Excessive surface acidity or heat from the sun kept most of them devoid of vegetation.[6]

Most of the coal-producing states are now implementing regulations to control the pollution problems associated with disposal of coal refuse. Pennsylvania has been carrying out a program of extinguishing abandoned-refuse-pile fires for the last decade, and in 1973, it adopted provisions for issuing permits for refuse sites and for controlling the air and water pollution problems. Some of the required control measures are: 18° maximum side slopes, 2 ft minimum thickness of refuse layers, and 50 ft clear space around the pile.[7] Indiana requires that all refuse and waste material from surface mining operations be removed or buried and that acid-forming material be inundated by water or covered by at least 2 ft of soil.[8]

RESEARCH ON USING OR SAFELY DISPOSING OF REFUSE

Various projects are being conducted to investigate possible uses of refuse and safe disposal methods.

The Crown Mine Drainage Field Site, operated by the Mining Pollution Control Branch of NERC-Cincinnati, has installed an asphaltic concrete parking apron over a refuse base course to investigate the water pollution problems associated with *refuse as a construction material*. The area is being monitored to determine the effect of the waste on water quality. The pavement was placed in three sections: refuse alone; refuse and fly ash; and refuse, fly ash, and lime. After 9 months, the water collected from the sites utilizing combinations of fly ash and fly ash and lime appeared to be unoffensive. The pH of these effluents has been nearly neutral, with low concentrations of aluminum, boron, iron, and sulfate ions. Water flowing from the section containing only refuse as a base material has become quite acidic (dropping nearly to pH 3), and rapidly increasing quantities of dissolved metals are being detected in these effluents. Monitoring is continuing in the area in an attempt to establish long-range trends.

At the Cross-Valley Highway near Wilkes-Barre, Pennsylvania, the Pennsylvania Department of Transportation is conducting a demonstration to show the engineering feasibility of using refuse as road fill. Several other construction sites in Wilkes-Barre have successfully used *refuse as fill material*. The West Virginia Highway Department, in conjunction with the Appalachian Regional Commission, is also studying the use of refuse in highway construction.

The State of Illinois has undertaken several test plots to experiment with *refuse revegetation techniques*. In addition, various other agencies and companies have performed reclamation projects to utilize or permanently dispose of refuse and to return the affected area to some productive use (Figure 4).

Figure 4. Refuse pile at Idamay, West Virginia, which has been graded, covered, and revegetated.

The first reports published by EPA concerning refuse reclamation presented the results of a project by the Truax-Traer Coal Company.[9,10] The object was to investigate the effectiveness of different thicknesses of *earth cover to reduce acid runoff* from refuse piles. In general, it was found that the acid can be controlled by covering and revegetating and that no significant difference is observed among 1-, 2-, or 3-ft soil covers. Reclamation costs for the project varied from $6,000 to $10,000 per acre.

To develop *sealing techniques* that could be applied to the surfaces of refuse piles, the Mining Pollution Control Branch conducted in-house studies at the Norton Mine Drainage Field Site.[11] Test plots of refuse were placed in the field to evaluate surface sealing by sodium silicate, sodium silicate – sodium aluminate, and carbonate bonding. Control plots were installed with no cover, clay cover, and plastic-sheet cover. In all cases, recently mined refuse was slow to oxidize and form acid. Results showed that: the plastic sheet was successful in repelling water for the total test period, but was of questionable practicality for full-scale application; sodium silicate was a more successful sealant when used alone rather than in conjunction with sodium aluminate; and carbonate bonding was highly dependent on proper compaction.

Presently, EPA is funding two demonstration grants in Indiana to show the effects of *hydrologic control, surface sealing, and permanent inundation*.

At Bruceville, Indiana, the Knox County Park and Recreation Board is conducting the first project to demonstrate methods for controlling mine drainage from the refuse and slurry of an abandoned underground mine. The area contains a refuse pile, which measures 60 ft thick in some places, and a slurry pond, which has broken through its dam and deposited material for several thousand yards downstream. A monitoring station is situated downstream from the project area to show the effectiveness of installing diversion ditches, grading and sealing the piles, and using evaporation ponds. The feasibility of using sewage sludge to reduce acid runoff will also be investigated.

The second project is at the Greene-Sullivan State Forest, where the Indiana Department of Natural Resources is demonstrating an economical method to abate acid mine drainage from surface coal mine refuse. The project area consists of a large pile and adjacent acid lake. The restoration program includes grading, covering, revegetating and permanently inundating a portion of the refuse. These procedures are designed to break the cycle of erosion, exposure of pyritic material, oxidation, acid formation, and erosion. Eventually, the area will be restored to recreational use.

Final solutions to the problems of refuse disposal, especially in relation to water quality, are still in the future. The various research and demonstration projects are showing short-term improvements; but study efforts must be continued to resolve the problems concerning the leaching and percolation of acid and heavy metals in a pile, the long term effects of surface sealing, the ultimate fate of "direct plant" vegetation, the utilization of refuse, and the stowing of refuse in underground mines.

REFERENCES

1. Simon, J. A., and M. E. Hopkins. Geology of Coal. In: S. M. Cassidy, ed., Elements of Practical Coal Mining. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York. 1973. pp. 11-39.
2. 1971 Minerals Yearbook, Volume 1 – Metals, Minerals, and Fuels. U.S. Bureau of Mines. Washington, D.C. 1973. pp. 329-395.
3. Deurbrouck, A. W. Coal Preparation 1973. Mining Congr. J. 60:65-67, February 1974.
4. Coalgate, J. L., D. J. Akers, and R. W. Frum. Gob Pile Stabilization, Reclamation, and Utilization. Office of Coal Research, Department of Interior, Report No. 75. Coal Research Bureau, School of Mines, West Virginia University. Washington D.C. May 1973. 127 pp.
5. Hummer, H. D., and L. J. Vogel. Refuse Removal and Disposal. In: Leonard and Mitchell, eds., Coal Preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York. 1968. pp. 16.3-16.37.
6. Schramm, J. R. Plant Colonization Studies on Black Wastes from Anthracite Mining in Pennsylvania. Trans. Am. Phil. Soc. 56:30-40, February 1966.
7. Commonwealth of Pennsylvania. Title 25. Rules and Regulations, Part 1, Department of Environmental Resources, Subpart C. Protection of Natural Resources, Art. 2. Water Resources, Ch. 100. Mine Resources Management, and Art. 3. Air Resources, Ch. 125. Coal Refuse Disposal Areas. May 17, 1973. 8 pp.
8. State of Indiana. Guidelines Respecting the Administration of an Act Regulating Surface Mining of Coal, Clay and Shale, Chapter 344, Act of 1967, as Amended by Acts of 1974. Division of Reclamation March 21, 1974. 53 pp.
9. Truax-Traer Coal Company. Control of Mine Drainage from Coal Mine Mineral Wastes, Phase I. 14010 DDH. Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, D.C. August 1971. 148 pp.
10. Kosowski, Z. V. Control of Mine Drainage from Coal Mine Mineral Wastes, Phase II. EPA-R2-73-230. Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, D.C. May 1973. 83 pp.
11. Scott, R. B. Sealing of Coal Refuse Piles. Project Report – Mining Pollution Control Branch. National Environmental Research Center, U.S. Environmental Protection Agency, Cincinnati, Ohio. July 1973. 15 pp.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 — 657-053/1080

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL ENVIRONMENTAL RESEARCH CENTER
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. ENVIRONMENTAL PROTECTION AGENCY
EPA-335

U.S.MAIL